

(19)



Europäisches Patentamt  
European Patent Office  
Office européen des brevets



(11)

EP 0 622 440 B1

12

(12)

## EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention  
of the grant of the patent:  
24.04.1996 Bulletin 1996/17

(51) Int Cl.<sup>6</sup>: C09K 11/80

(21) Application number: 94301329.2

(22) Date of filing: 24.02.1994

(54) **Phosphorescent phosphor**  
Phosphoreszentes Phosphor  
Matériau phosphorescent

(84) Designated Contracting States:  
CH DE DK ES FR GB IT LI NL PT

(30) Priority: 28.04.1993 JP 103310/93  
21.01.1994 JP 4984/94

(43) Date of publication of application:  
02.11.1994 Bulletin 1994/44

(73) Proprietor: NEMOTO & CO., LTD.  
Tokyo 167 (JP)

(72) Inventors:  
• Murayam, Yoshihiko  
Tokyo 167 (JP)

- Takeuchi, Nobuyoshi  
Tokyo 167 (JP)
- Aoki, Yasumitsu  
Tokyo 167 (JP)
- Matsuzawa, Takashi  
Tokyo 167 (JP)

(74) Representative: Cresswell, Thomas Anthony  
J.A. KEMP & CO.  
14 South Square  
Gray's Inn  
London WC1R 5LX (GB)

(56) References cited:  
EP-A- 0 094 132 DE-A- 1 811 731

EP 0 622 440 B1

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

## Description

The present invention relates to phosphorescent phosphors, and more particularly to a novel phosphorescent phosphor which shows excellent photo-resistance required for the phosphorescent phosphor to be utilized both indoors and outdoors mainly as a night-time display, and which shows extremely long afterglow characteristics.

Generally, the afterglow time of a fluorescent substance is short, i.e., the light emitted from the fluorescent substance decays immediately after it has been removed from the source of excitation. Unlike such a fluorescent substance, some substances emit light after having absorbed ultraviolet radiation or the like and the afterglow that can be visually observed continues for a considerable time (ranging from several tens of minutes to several hours) after the source of stimulus is cut off. Such substances are called phosphorescent phosphors.

As phosphorescent phosphors, sulfide phosphorescent phosphors are known. Examples of sulfide phosphorescent phosphors include  $\text{CaS} : \text{Bi}$  (which emits light of violet blue),  $\text{CaSrS} : \text{Bi}$  (which emits light of blue),  $\text{ZnS} : \text{Cu}$  (which emits light of green) and  $\text{ZnCdS} : \text{Cu}$  (which emits light of yellow or orange). However, these sulfide phosphorescent phosphors are chemically unstable and show degraded light resistance, i.e. they have drawbacks that must be solved for practical use.

The most extensively used phosphorescent phosphor among such sulfide phosphorescent phosphors is zinc sulfide phosphorescent phosphor ( $\text{ZnS} : \text{Cu}$ ). However, zinc sulfide phosphorescent phosphor is decomposed by ultraviolet radiation in the presence of moisture and thus blackens or shows reduced luminance. Therefore, it is difficult to use this phosphorescent phosphor in applications which require it to be placed outdoors and exposed to direct sunlight, that is, its use is limited to luminous clocks/watches and instrument dials, evacuation guiding signs or indoor night-time display.

Even when zinc sulfide phosphorescent phosphor is used for a luminous clock, since the afterglow thereof which allows the time to be visually recognized lasts only from 30 minutes to 2 hours, a radioactive substance must be doped to the phosphorescent phosphor and a self-luminous paint which keeps emitting light by absorbing an energy of radiation from radioactive substance must be employed.

In view of the aforementioned problems of the prior art, an object of the present invention is to provide a phosphorescent phosphor which shows afterglow characteristics that last much longer than those of presently available sulfide phosphorescent phosphors, and which is chemically stable and shows excellent photo-resistance over a long time.

EP-A-0094132 discloses a luminescent screen, the luminescent layer of which comprises an alkaline earth metal aluminate activated with europium or lead. The alkaline earth metal is strontium alone or strontium with up to 25% replaced by calcium.

DE-A-1811731 also describes an alkaline earth metal aluminate activated by bivalent europium, the aluminate having the formula  $\text{Ba}_{x+0.2}\text{Sr}_y\text{Eu}_p\text{Al}_2\text{O}_4$ . This luminescent aluminate is said to be useful in low pressure mercury vapour discharge lamps.

The present inventors took note of alkaline earth metal type aluminates activated by europium or the like, which is a phosphorescent phosphor completely different from conventional sulfide phosphorescent phosphors, conducted various experiments and developed a phosphor that shows afterglow characteristics which last much longer than those of currently available sulfide phosphorescent phosphors, and which is chemically stable and shows excellent photo-resistance. It was concluded that this phosphorescent phosphor could solve the problems of the prior art and be employed as a luminous paint or pigment in various applications where it could be detected visually for a night without requiring a radioactive dopant.

The present invention therefore provides a phosphor which comprises a matrix of formula  $\text{MAl}_2\text{O}_4$  wherein M is calcium, strontium or barium, the matrix comprising europium as activator and, as co-activator, at least one element selected from lanthanum, cerium, praseodymium, neodymium, samarium, gadolinium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, tin and bismuth.

The present invention further provides a phosphor comprising a matrix of formula  $\text{MAl}_2\text{O}_4$  wherein M comprises at least two metals selected from calcium, strontium, barium and magnesium, the matrix comprising europium as activator and, as co-activator at least one element selected from lanthanum, cerium, praseodymium, neodymium, samarium, gadolinium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, tin and bismuth.

In a further aspect of the invention the phosphor comprises a matrix of formula  $(\text{M}'_x\text{M}''_y)\text{Al}_2\text{O}_4$  wherein  $x+y=1$  and  $\text{M}'$  and  $\text{M}''$ , which are different, are each a metal selected from calcium, strontium, barium and magnesium, the matrix comprising europium as activator and, as co-activator, at least one element selected from lanthanum, cerium, praseodymium, neodymium, samarium, gadolinium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, tin and bismuth.

In a preferred form the europium activator is contained in an amount of 0.001 mol% to 10 mol% in terms of mol% relative to the metal or metals in the matrix.

In another preferred form the or each activator is contained in an amount of 0.001 mol% to 10 mol% in terms of mol% relative to the metal or metals in the matrix. In one aspect the total amount of co-activator is 0.001 mol% to 10

mol% relative to the metal or metals in the matrix.

In still another preferred form, the phosphorescent phosphor may show a glow peak of thermo-luminescence in a high-temperature region of 50°C or above when irradiated by ultraviolet or visible rays having a wavelength of 200 to 450 nm at room temperature.

Additionally, it is possible to add 1 - 10% by weight of boric acid as flux to the starting material to perform the aforementioned synthesis of the phosphorescent phosphors. In this case, if the amount of flux is less than 1% by weight, the effect of flux vanishes and if the amount of flux exceeds 10% by weight, flux is solidified, so that it becomes difficult to perform the milling and sieving which must be performed later.

A phosphorescent phosphor of the invention, as described above, may be mixed with a plastic material, rubber, glass or ink to form a composition.

The phosphor may be used to impart afterglow characteristics to a substrate. A further aspect of the present invention is therefore a method of imparting afterglow characteristics to a substrate selected from a gauge, clock dial, safety sign, vehicle, key, key-hole, traffic sign, guard rail, fishing buoy, helmet, signpost, electrical switch, writing instrument, map, toy or sportsball, which method comprises applying to the said substrate a phosphor as described above.

In the accompanying drawings.

Fig. 1 is a graph showing the results of analysis of a crystal structure of  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor by XRD;

Fig. 2 is a graph showing the excitation spectrum of  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor and the emission spectrum thereof obtained 30 minutes after cessation of excitation;

Fig. 3 is a graph showing the results of the comparison between the afterglow characteristics of  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor and the afterglow characteristics of ZnS : Cu phosphorescent phosphor;

Fig. 4 is a graph showing the thermo-luminescence characteristics of  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor.

Fig. 5 is a graph showing the results of the comparison between the afterglow characteristics of  $\text{SrAl}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor and the afterglow characteristics of ZnS : Cu phosphorescent phosphor;

Fig. 6 is a graph showing the thermo-luminescence characteristics of  $\text{SrAl}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor;

Fig. 7 is a graph showing the thermo-luminescence characteristics of  $\text{SrAl}_2\text{O}_4$  : Eu, Nd phosphorescent phosphor;

Fig. 8 is a graph showing the results of analysis of the crystal structure of  $\text{CaAl}_2\text{O}_4$  : Eu phosphorescent phosphor by XRD;

Fig. 9 is a graph showing the thermo-luminescence characteristics of  $\text{CaAl}_2\text{O}_4$  : Eu, phosphorescent phosphor which employs neodymium or samarium as the co-activator;

Fig. 10 is a graph showing the thermo-luminescence characteristics of  $\text{CaAl}_2\text{O}_4$  : Eu phosphorescent phosphor which employs dysprosium or thorium as the co-activator;

Fig. 11 is a graph showing the emission spectrum of  $\text{CaAl}_2\text{O}_4$  : Eu phosphorescent phosphor obtained 5 minutes after cessation of excitation;

Fig. 12 is a graph showing the results of the comparison between the afterglow characteristics of  $\text{CaAl}_2\text{O}_4$  : Eu, Sm phosphorescent phosphor and  $\text{CaAl}_2\text{O}_4$  : Eu, Nd phosphorescent phosphor and the afterglow characteristics of ZnS : Cu phosphorescent phosphor;

Fig. 13 is a graph showing the excitation spectrum of  $\text{BaAl}_2\text{O}_4$  : Eu, Nd phosphorescent phosphor and the emission spectrum thereof obtained 30 minutes after cessation of excitation;

Fig. 14 is a graph showing the excitation spectrum of  $\text{BaAl}_2\text{O}_4$  : Eu, Sm phosphorescent phosphor and the emission spectrum thereof obtained 30 minutes after cessation of excitation;

Fig. 15 is a graph showing the emission spectrum of  $\text{SrO} \cdot 5\text{CaO} \cdot 5\text{Al}_2\text{O}_3$  : Eu, Dy phosphorescent phosphor;

Fig. 16 is a graph showing the results of the comparison between the afterglow characteristics of  $\text{Sr}_x\text{Ca}_{1-x}\text{Al}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor and the afterglow characteristics of ZnS : Cu phosphorescent phosphor and  $\text{CaSrS}$  : Bi phosphorescent phosphor;

Fig. 17 is a graph showing the results of the comparison between the afterglow characteristics of  $\text{Sr}_x\text{Ba}_{1-x}\text{Al}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor and the afterglow characteristics of ZnS : Cu phosphorescent phosphor; and

Fig. 18 is a graph showing the results of the comparison between the afterglow characteristics of  $\text{Sr}_x\text{Mg}_{1-x}\text{Al}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor and the afterglow characteristics of ZnS : Cu phosphorescent phosphor.

The invention will be further described in the Examples which follow, which differ from each other in the type (M) of metal element, the concentration of europium activator and the type and concentration of co-activator. The Comparative Examples illustrate the preparation and testing of phosphors which include europium as activator but contain no co-activator.

# Comparative Example : Synthesis of $\text{SrAl}_2\text{O}_4$ : Eu phosphorescent phosphor and characteristics thereof

## Sample 1-(1)

As an activator 1.76 g (0.005 mol) of europium oxide ( $\text{Eu}_2\text{O}_3$ ) was added to 146.1 g (0.99 mol) of strontium carbonate having reagent grade and 102 g (1 mol) of alumina having reagent grade and, further, 5 g (0.08 mol) of boric acid was added as flux thereto. After the resultant mixture was sufficiently mixed using a ball mill, the sample was fired for 1 hour at 1300 °C in a stream of nitrogen-hydrogen mixture gas (97 : 3) (flow rate : 0.1 liter/min) using an electric furnace. Thereafter, the sample was cooled to a room temperature for about 1 hour. The obtained powder compound was sieved having 100 mesh to obtain phosphorescent phosphor sample 1-(1).

Fig. 1 shows the results of analysis of the crystal structure of the obtained phosphorescent phosphor by XRD (X-ray diffractionmetry). The diffraction peak characteristics showed that the obtained phosphorescent phosphor was  $\text{SrAl}_2\text{O}_4$  having spinel structure.

Fig. 2 shows the excitation spectrum of that phosphorescent phosphor and the afterglow emission spectrum thereof obtained after removal from the source of light. The peak wavelength of the emission spectrum of  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor is about 520 nm which indicates green.

Fig. 3 and Table 2 show the results of the comparison between the measurements of the afterglow characteristics of the obtained  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor and those of  $\alpha\text{ZnS}$  : Cu phosphorescent phosphor which is available on the market and which emits light of green (manufactured by Nemoto & Co., LTD : trade mark : GSS, and the wavelength of emission peak : 530 nm).

The afterglow characteristics were measured as follows : 0.05 g of the obtained phosphorescent phosphor powder was taken on a sample plate having an inner diameter of 8 mm and made of aluminum (sample thickness : 0.1 g/cm<sup>2</sup>), and that sample was left in the darkness for about 15 hours to remove afterglow. Thereafter, the sample was irradiated by a D65 standard light source at 200 lux for 10 minutes, and the obtained afterglow was measured using a luminance measuring device which employed a photo-multiplier.

As seen from Fig. 3, the afterglow of the  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor is bright and decay is slow. As the time passes, the difference in the intensity of afterglow between  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor and the  $\text{ZnS}$  : Cu phosphorescent phosphor increases. In Figure 3, the broken line indicates the level of visually recognizable light intensity (corresponding to a luminance of about 0.3 mCd/m<sup>2</sup>). It can be inferred from this broken line which indicates the afterglow characteristic of  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor that afterglow thereof will be recognized 24 hours later. When afterglow of  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor was actually measured 15 hours after excitation, it was observed as visually recognizable.

Table 2 shows the intensity of afterglow of sample 1-(1) which was measured 10 minutes, 30 minutes and 100 minutes after excitation, respectively, in terms of the relative value to the light intensity of the  $\text{ZnS}$  : Cu phosphorescent phosphor. It can be seen from Table 2 that the afterglow luminance of  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor according to the present invention, measured 10 minutes after excitation, is 2.9 times that of  $\text{ZnS}$  : Cu phosphorescent phosphor, and that the afterglow luminance of the  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor, measured 100 minutes after excitation, is 17 times that of  $\text{ZnS}$  : Cu phosphorescent phosphor.

Fig. 4 shows the results of the examination of the thermo-luminescence characteristics (glow curves) of  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor which were measured when the phosphorescent phosphor was illuminated at a temperature from room temperature to 250 °C using a TLD reader (KYOKKO TLD-2000 system). Fig. 4 shows that the thermo-luminescence characteristics of the phosphor have three glow peaks at about 40°C, 90°C and 130°C, and that the peak at 130°C is the main glow peak. The glow curve of the  $\text{ZnS}$  : Cu phosphorescent phosphor, indicated by the broken line in Fig. 4, peaks at about 40°C. It is believed that a deep trapping level of  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor, corresponding to a high temperature of 50°C or above, increases the time constant of afterglow, and thus enhances the afterglow characteristics over a long time.

$\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor samples (sample 1-(2) through 1-(7)) having the compositions shown in Table 1 were manufactured in the same manner as that of sample 1-(1), except the concentration of europium was altered as shown in Table 1.

TABLE 1

Sample	Material Mixing Ratio		
	Strontium carbonate	Alumina	Europium
Sample 1-(2)	0.99998 mol	1.0 mol	0.00001 mol

Continuation of the Table on the next page

TABLE 1 (continued)

Sample	Material Mixing Ratio		
	Strontium carbonate	Alumina	Europium
(3)	0.9999	1.0	0.00005
(4)	0.995	1.0	0.0025
(5)	0.97	1.0	0.015
(6)	0.90	1.0	0.05
(7)	0.80	1.0	0.1

The results of the examination of the afterglow characteristics of these samples 1-(2) through 1-(7), together with those of sample 1-(1), are shown in Table 2.

It can be seen from Table 2 that if the amount of added Eu is between 0.0025 mol and 0.05 mol, the afterglow characteristic of  $\text{SrAl}_2\text{O}_4$  is better than the  $\text{ZnS} : \text{Cu}$  phosphorescent phosphor and the afterglow luminance 10 minutes after is also better than that of the  $\text{ZnS} : \text{Cu}$  phosphorescent phosphor. Furthermore, even when the proportion of Eu is 0.00001 mol or 0.1 mol, the afterglow of the  $\text{SrAl}_2\text{O}_4 : \text{Eu}$  phosphorescent phosphor has a higher luminance than that of  $\text{ZnS} : \text{Cu}$  phosphorescent phosphor 30 minutes after excitation ceases.

Further, since Eu is expensive, if economy and deterioration in the afterglow characteristics due to concentration quenching are taken into consideration, addition of Eu at a proportion of 10 mol% or above is meaningless. Conversely, when judging in terms of afterglow characteristics, although the luminance of  $\text{SrAl}_2\text{O}_4$  10 minutes after excitation is lower than  $\text{ZnS} : \text{Cu}$  phosphorescent phosphor when the amount of Eu is between 0.00001 mol (0.001 mol%) and 0.00005 mol (0.005 mol%), it has a higher luminance than  $\text{ZnS} : \text{Cu}$  phosphorescent phosphor 10 minutes after cessation of excitation, thereby indicating that the effect of added Eu as an activator is evident.

Further, since  $\text{SrAl}_2\text{O}_4 : \text{Eu}$  phosphorescent phosphor is an oxide, it is chemically stable and shows excellent photo-resistance when compared with conventional sulfide phosphorescent phosphors (see Tables 24, 25).

TABLE 2

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
$\text{ZnS} : \text{Cu}$ Std.	1.00	1.00	1.00
Sample 1-(1)	2.90	6.61	17.0
(2)	0.41	1.20	3.10
(3)	0.56	1.50	4.80
(4)	2.40	4.50	13.5
(5)	3.01	7.04	19.2
(6)	1.10	2.70	10.3
(7)	0.32	1.11	3.02

Example 1: Synthesis of  $\text{SrAl}_2\text{O}_4 : \text{Eu}$ , Dy phosphorescent phosphor and characteristics thereof

Sample 2-(1)

As an activator and as a co-activator, 1.76 g (0.005 mol) of europium oxide ( $\text{Eu}_2\text{O}_3$ ) and 1.87 g (0.005 mol) of dysprosium oxide ( $\text{Dy}_2\text{O}_3$ ) were added, respectively to 144.6 g (0.98 mol) of strontium carbonate having reagent grade and 102 g (1 mol) of alumina having reagent grade. Further, for example, 5 g (0.08 mol) of boric acid is added thereto as flux. After the resultant mixture was sufficiently mixed using a ball mill, the sample was fired for 1 hour at 1300 °C in a stream of nitrogen-hydrogen mixture gas (97 : 3) (flow rate : 0.1 liter/min) using an electric furnace. Thereafter, the sample was cooled to a room temperature for about 1 hour. The obtained powder compound was sieved having 100 mesh to obtain phosphorescent phosphor sample 2-(1).

The afterglow characteristics of this phosphorescent phosphor were examined in the same manner as that described above. The results of the examination are shown in sample 2-(1) of Fig. 5 and Table 4.

As can be seen from Fig. 5, the afterglow luminance of  $\text{SrAl}_2\text{O}_4 : \text{Eu}$ , Dy phosphorescent phosphor according to

the present invention, particularly, the luminance of afterglow at an initial stage thereof is much higher than that of ZnS : Cu phosphorescent phosphor, and the decay time constant thereof is high. These indicate that  $\text{SrAl}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor according to the present invention is an epoch-making high-luminance phosphorescent phosphor. It can be seen from both the visually recognizable afterglow intensity level and the afterglow characteristic of this  $\text{SrAl}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor, shown in Fig. 5, that afterglow of this phosphorescent phosphor will be recognized even 16 hours later.

Table 4 shows the intensity of afterglow of sample 2-(1) which was measured 10 minutes, 30 minutes and 100 minutes, respectively after excitation in terms of the relative value to the afterglow luminescence intensity of ZnS : Cu phosphorescent phosphor. It can be seen from Table 4 that the afterglow luminance of  $\text{SrAl}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor according to the present invention, measured 10 minutes after excitation, is 12.5 times that of ZnS : Cu phosphorescent phosphor, and that the afterglow luminance of  $\text{SrAl}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor according to the present invention, measured 100 minutes after excitation, is 37 times that of ZnS : Cu phosphorescent phosphor.

Fig. 6 shows the results of the examination of the thermo-luminescence characteristics (glow curves) of  $\text{SrAl}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor previously irradiated which was conducted in a temperature range between the room temperature and 250°C. It can be seen from Figs. 6 and 4 that addition of Dy as a co-activator has changed the main glow peak temperature of thermo-luminescence from 130 °C to 90°C. A high intensity of emission from the trapping level corresponding to 90°C is considered the cause of a higher luminance of afterglow at the initial stage thereof than that of  $\text{SrAl}_2\text{O}_4$  : Eu phosphorescent phosphor.

#### Samples 2-(2) through 2-(7)

$\text{SrAl}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor samples (sample 2-(2) through 2-(7)) having compositions shown in Table 3 were manufactured in the same manner as that of sample 2-(1) with the exception that the proportion of dysprosium was altered, as shown in Table 3.

TABLE 3

Sample	Material Mixing Ratio			
	Strontium carbonate		Europium	Dysprosium
Sample 2-(2)	0.98998 mol	1.1 mol	0.005 mol	0.00001 mol
(3)	0.9899	1.0	0.005	0.00005
(4)	0.985	1.0	0.005	0.0025
(5)	0.94	1.0	0.005	0.025
(6)	0.92	1.0	0.005	0.035
(7)	0.79	1.0	0.005	0.10

The results of the examination of the afterglow characteristics of these samples 2-(2) through 2-(7), together with those of sample 2-(1), are shown in Table 4.

It can be seen from Table 4 that, considering that  $\text{SrAl}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor has a more excellent afterglow characteristic and more excellent luminance 10 minutes after excitation than ZnS : Cu phosphorescent phosphor, the optimum proportion of Dy, served as the co-activator, is between 0.0025 mol and 0.05 mol. However, even when the proportion of Dy is 0.00001 mol, afterglow of  $\text{SrAl}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor has a higher luminance than that of ZnS : Cu phosphorescent phosphor 30 minutes after excitation ceases. This fact indicates the effects of added Eu and Dy as an activator and a co-activator, respectively. Further, since Dy is expensive, if economy and deterioration in the afterglow characteristics due to concentration quenching are taken into consideration, addition of Dy at a proportion of 0.1 mol (10 mol%) or above is meaningless.

Further, since  $\text{SrAl}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor is an oxide, it is chemically stable and shows excellent photo-resistance when compared with conventional sulfide phosphorescent phosphors (see Tables 24, 25).

Table 4

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
ZnS: Cu Std	1.00	1.00	1.00

Continuation of the Table on the next page

Table 4 (continued)

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Sample 2-(1)	12.5	19.6	37.0
Sample 2-(2)	0.943	1.57	2.00
Sample 2-(3)	1.5	1.7	2.1
Sample 2-(4)	11.7	17.3	22.1
Sample 2-(5)	20.4	28.8	40.2
Sample 2-(6)	18.6	26.3	36.4
Sample 2-(7)	1.95	2.66	3.30

Next, a phosphorescent phosphor which employs strontium as the metal element (M) and which employs europium as an activator and neodymium as a co-activator will be described as Example 2.

Example 2 : Synthesis of  $\text{SrAl}_2\text{O}_4$  : Eu, Nd phosphorescent phosphor and characteristics thereof

Samples 3-(1) through 3-(7)

$\text{SrAl}_2\text{O}_4$  : Eu, Nd phosphorescent phosphor samples having compositions shown in Table 5 were manufactured in the same manner as that described above with the exception that the proportion of neodymium was altered, as shown in Table 5.

TABLE 5

Sample	Material Mixing Ratio			
	Strontium carbonate	Alumina	Europium	Neodymium
Sample 3-(1)	0.98998 mol	1.0 mol	0.005 mol	0.00001 mol
(2)	0.9899	1.0	0.005	0.00005
(3)	0.985	1.0	0.005	0.0025
(4)	0.980	1.0	0.005	0.005
(5)	0.94	1.0	0.005	0.025
(6)	0.92	1.0	0.005	0.035
(7)	0.79	1.0	0.005	0.10

The results of the examination of the afterglow characteristics of these samples 3-(1) through 3-(7) are shown in Table 6.

TABLE 6

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
ZnS:Cu Std.	1.00	1.00	1.00
Sample 3-(1)	0.71	0.91	1.12
(2)	0.73	1.02	1.25
(3)	6.20	8.50	11.14
(4)	9.05	11.75	14.29
(5)	9.01	11.55	13.98
(6)	8.50	10.21	11.96
(7)	2.35	2.54	2.86

It can be seen from Table 6 that when the amount of added Nd as a co-activator is between 0.025 and 0.10 mol,  $\text{SrAl}_2\text{O}_4 : \text{Eu}$ , Nd phosphorescent phosphor has a more excellent afterglow characteristic and a higher luminance 10 minutes after excitation than  $\text{ZnS} : \text{Cu}$  phosphorescent phosphor. However, even when the proportion of Nd is 0.00001 mol, afterglow of  $\text{SrAl}_2\text{O}_4 : \text{Eu}$ , Nd phosphorescent phosphor has a higher luminance than that of  $\text{ZnS} : \text{Cu}$  phosphorescent phosphor 60 minutes after excitation ceases. This fact indicates the effects of added Eu and Nd as an activator and a co-activator, respectively. Further, since Nd is expensive, if economy and deterioration in the afterglow characteristics due to concentration quenching are taken into consideration, addition of Nd at a proportion of 0.1 mol (10 mol%) or above is meaningless.

Further, since  $\text{SrAl}_2\text{O}_4 : \text{Eu}$ , Nd phosphorescent phosphor is an oxide, it is chemically stable and shows excellent photo-resistance when compared with conventional sulfide phosphorescent phosphors (see Tables 24, 25).

Fig. 7 shows the results of the examination of the thermo-luminescence characteristics (glow curves) of  $\text{SrAl}_2\text{O}_4 : \text{Eu}$ , Nd phosphorescent phosphor sample 3-(4) previously irradiated which was conducted in a temperature range between the room temperature and 250°C. It can be seen from Fig. 7 that the main peak temperature of thermo-luminescence of the phosphorescent phosphor in which Nd is doped as a co-activator is about 50°C.

Next, a phosphorescent phosphor which employs strontium as the metal element (M), which employs europium as an activator and, which employs, as a co-activator, one element selected from a group consisting of lanthanum, cerium, praseodymium, samarium, gadolinium, holmium, erbium, thulium, ytterbium, lutetium, tin, bismuth will be described as example 3.

In the case of europium, neodymium or dysprosium as an activator or a co-activator, addition thereof at a proportion of 0.005 mol relative to the metal element (M) assured the high afterglow luminance. With this fact taken into consideration, only the samples in which the Eu concentration of the activator is 0.5 mol% (0.005 mol) and the concentration of the co-activator is 0.5 mol% (0.005 mol) are shown.

#### Example 3: Advantage of doping of another co-activator to $\text{SrAl}_2\text{O}_4 : \text{Eu}$ phosphorescent phosphor

Table 7 shows the results of the examination of the afterglow characteristics of the phosphorescent phosphor samples to which lanthanum, cerium, praseodymium, samarium, gadolinium, holmium, erbium, thulium, ytterbium, lutetium, tin and bismuth were added, respectively, as the co-activator.

As can be seen from Table 7, the afterglow characteristics of any of  $\text{SrAl}_2\text{O}_4 : \text{Eu}$  phosphorescent phosphors doped with co-activators, improved as the time of more than 30 or 100 minutes elapsed after cessation of excitation, as compared with those of currently available  $\text{ZnS} : \text{Cu}$  phosphorescent phosphor which was used as the comparison, and were thus at a level which allowed the phosphorescent phosphor to be put into practical use.

Since  $\text{SrAl}_2\text{O}_4 : \text{Eu}$  phosphorescent phosphor is an oxide, it is chemically stable and shows excellent photo-resistance when compared with conventional sulfide phosphorescent phosphors (see Tables 24, 25).

Table 7

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
ZnS:Cu Std	1.00	1.00	1.00
$\text{SrAl}_2\text{O}_4 : \text{Eu, La}$	0.33	0.74	1.14
$\text{SrAl}_2\text{O}_4 : \text{Eu, Ce}$	0.46	0.93	1.35
$\text{SrAl}_2\text{O}_4 : \text{Eu, Pr}$	1.24	2.63	7.51
$\text{SrAl}_2\text{O}_4 : \text{Eu, Sm}$	3.40	4.82	9.0
$\text{SrAl}_2\text{O}_4 : \text{Eu, Gd}$	0.51	1.30	2.27
$\text{SrAl}_2\text{O}_4 : \text{Eu, Ho}$	1.06	2.09	6.29
$\text{SrAl}_2\text{O}_4 : \text{Eu, Er}$	0.63	1.43	3.18
$\text{SrAl}_2\text{O}_4 : \text{Eu, Tm}$	0.81	1.53	3.28
$\text{SrAl}_2\text{O}_4 : \text{Eu, Yb}$	0.61	1.28	2.99
$\text{SrAl}_2\text{O}_4 : \text{Eu, Lu}$	0.49	1.01	3.40
$\text{SrAl}_2\text{O}_4 : \text{Eu, Sn}$	1.93	3.61	7.92
$\text{SrAl}_2\text{O}_4 : \text{Eu, Bi}$	0.72	1.77	5.55



Comparative Example 2 and Example 4: Synthesis of  $\text{CaAl}_2\text{O}_4$  : Eu phosphorescent phosphor and characteristics thereof

Europium oxide ( $\text{Eu}_2\text{O}_3$ ) as an activator was doped to calcium carbonate having reagent grade and alumina having reagent grade and 5 g (0.08 mol) of boric acid was doped thereto as flux.

Europium oxide ( $\text{Eu}_2\text{O}_3$ ) and either of lanthanum oxide, cerium oxide, praseodymium oxide, neodymium oxide, samarium oxide, gadolinium oxide, dysprosium oxide, holmium oxide, erbium oxide, thulium oxide, ytterbium oxide, lutetium oxide, tin oxide and bismuth oxide were added, as an activator and a co-activator respectively, to calcium carbonate having reagent grade and alumina having reagent grade and 5 g (0.08 mol) of boric acid was added thereto as flux. After the resultant mixture was sufficiently mixed using a ball mill, the sample was fired for 1 hour at 1300 °C in a stream of nitrogen-hydrogen mixture gas (97 : 3) (flow rate : 0.1 liter/min) using an electric furnace. Thereafter, the sample was cooled to a room temperature for about 1 hour. The obtained powder compound was sieved having 100 mesh to obtain phosphorescent phosphor sample 5-(1) through 5-(42).

Fig. 8 shows the results of analysis of the crystal structure of the obtained sample 5-(2) by XRD. It was discovered from the diffraction peak characteristics that the obtained phosphorescent phosphor was monoclinic  $\text{CaAl}_2\text{O}_4$ .

Figs. 9 and 10 show the results of the examination of the thermo-luminescence characteristics (glow curves) of samples 5-(10), 5-(16), 5-(22) and 5-(23) which employed, as the co-activator, neodymium, samarium, dysprosium, and thulium, respectively. In either case, the glow curve has a peak in the high-temperature range of 50°C or above. This implies that these phosphorescent phosphors have long-lasting afterglow characteristics. The emission spectrum of afterglow of each of the samples had a peak at about 442 nm, as shown in Fig. 11, and the color of afterglow was thus blue.

The afterglow characteristics of each of the samples were compared with the afterglow characteristics of currently available  $\text{CaSrS} : \text{Bi}$  phosphorescent phosphor which emitted light of blue (manufactured by Nemoto Co., LTD trade-mark: BA-S, and the wavelength of emission peak : 454 nm) in Tables 8 to 13.

As shown in Tables 9 to 13, addition of a co-activator increased the afterglow luminance obtained when Europium alone was added as activator (see Table 8). This happened whichever type of co-activator was employed. Particularly, addition of Nd, Sm and Tm was greatly effective, and thus provided a super high luminance blue emission color phosphorescent phosphor which was an order of magnitude brighter. Fig. 12 shows the results of the examination of the long-lasting afterglow of these high-luminance phosphorescent phosphors obtained by adding Nd, Sm and Tm as a co-activator.

In more detail, Table 8 shows the afterglow characteristics of phosphorescent phosphors which employ calcium and europium as the metal element (M) and the activator, respectively, and which employ no co-activator, the phosphorescent phosphors being shown in 5-(1) through 5-(6).

Table 8

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. $\text{CaSrS} : \text{Bi}$	1.00	1.00	1.00
5-(1) $\text{CaAl}_2\text{O}_4 : \text{Eu}$ (Eu: 0.001 mol%)	0.18	0.16	0.14
5-(2) $\text{CaAl}_2\text{O}_4 : \text{Eu}$ (Eu: 0.01 mol%)	0.21	0.18	0.17
5-(3) $\text{CaAl}_2\text{O}_4 : \text{Eu}$ (Eu: 0.1 mol%)	0.25	0.27	0.35
5-(4) $\text{CaAl}_2\text{O}_4 : \text{Eu}$ (Eu: 0.5 mol%)	0.41	0.60	0.90
5-(5) $\text{CaAl}_2\text{O}_4 : \text{Eu}$ (Eu: 2.5 mol%)	0.37	0.45	0.65
5-(6) $\text{CaAl}_2\text{O}_4 : \text{Eu}$ (Eu: 10 mol%)	0.25	0.28	0.39

Table 9 shows the afterglow characteristics of phosphorescent phosphors which employ calcium, europium and neodymium as the metal element (M), the activator, and the co-activator, respectively, the phosphorescent phosphors being shown in 5-(7) through 5-(12).

Table 9

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. CaSrS:Bi	1.00	1.00	1.00
5-(7) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd (Eu: 0.5 mol% Nd: 0.001 mol%)	0.53	0.78	1.01
5-(8) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd (Eu: 0.5 mol% Nd: 0.01 mol%)	1.05	1.53	2.60
5-(9) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd (Eu: 0.5 mol% Nd: 0.1 mol%)	8.68	11.8	20.3
5-(10) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd (Eu: 0.5 mol% Nd: 0.5 mol%)	9.87	14.0	25.0
5-(11) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd (Eu: 0.5 mol% Nd: 2.5 mol%)	3.18	4.51	8.05
5-(12) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd (Eu: 0.5 mol% Nd: 10 mol%)	0.84	1.18	2.02

Table 10 shows the afterglow characteristics of phosphorescent phosphors which employ calcium, europium and samarium as the metal element (M), the activator, and the co-activator, respectively, the phosphorescent phosphors being shown in 5-(13) through 5-(18).

Table 10

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. CaSrS:Bi	1.00	1.00	1.00
5-(13) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Sm (Eu: 0.5 mol% Sm: 0.001 mol%)	0.71	0.98	1.23
5-(14) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Sm (Eu: 0.5 mol% Sm: 0.01 mol%)	0.94	1.43	2.55
5-(15) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Sm (Eu: 0.5 mol% Sm: 0.1 mol%)	4.21	6.32	11.30
5-(16) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Sm (Eu: 0.5 mol% Sm: 0.5 mol%)	4.61	7.00	12.5
5-(17) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Sm (Eu: 0.5 mol% Sm: 2.5 mol%)	2.14	3.25	5.80
5-(18) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Sm (Eu: 0.5 mol% Sm: 10 mol%)	0.63	0.96	1.71

Table 11 shows the afterglow characteristics of phosphorescent phosphors which employ calcium, europium and dysprosium as the metal element (M), the activator, and the co-activator, respectively, the phosphorescent phosphors

being shown in 5-(19) through 5-(24).

Table 11

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. CaSrS:Bi	1.00	1.00	1.00
5-(19) $\text{CaAl}_2\text{O}_4\text{:Eu,Dy}$ (Eu: 0.5 mol% Dy: 0.001 mol%)	0.30	0.24	0.20
5-(20) $\text{CaAl}_2\text{O}_4\text{:Eu,Dy}$ (Eu: 0.5 mol% Dy: 0.01 mol%)	0.41	0.39	0.35
5-(21) $\text{CaAl}_2\text{O}_4\text{:Eu,Dy}$ (Eu: 0.5 mol% Dy: 0.1 mol%)	0.52	0.60	0.76
5-(22) $\text{CaAl}_2\text{O}_4\text{:Eu,Dy}$ (Eu: 0.5 mol% Dy: 0.5 mol%)	0.76	0.90	1.25
5-(23) $\text{CaAl}_2\text{O}_4\text{:Eu,Dy}$ (Eu: 0.5 mol% Dy: 2.5 mol%)	0.84	1.18	1.76
5-(24) $\text{CaAl}_2\text{O}_4\text{:Eu,Dy}$ (Eu: 0.5 mol% Dy: 10 mol%)	0.50	0.58	0.76

Table 12 shows the afterglow characteristics of phosphorescent phosphors which employ calcium, europium and thulium as the metal element (M), the activator, and the co-activator, respectively, the phosphorescent phosphors being shown in 5-(25) through 5-(30).

Table 12

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. CaSrS:Bi	1.00	1.00	1.00
5-(25) $\text{CaAl}_2\text{O}_4\text{:Eu,Tm}$ (Eu: 0.5 mol% Dy: 0.001 mol%)	1.04	1.36	1.81
5-(26) $\text{CaAl}_2\text{O}_4\text{:Eu,Tm}$ (Eu: 0.5 mol% Tm: 0.01 mol%)	2.09	2.65	3.75
5-(27) $\text{CaAl}_2\text{O}_4\text{:Eu,Tm}$ (Eu: 0.5 mol% Tm: 0.1 mol%)	4.89	5.78	8.70
5-(28) $\text{CaAl}_2\text{O}_4\text{:Eu,Tm}$ (Eu: 0.5 mol% Tm: 0.5 mol%)	6.55	9.04	18.6
5-(29) $\text{CaAl}_2\text{O}_4\text{:Eu,Tm}$ (Eu: 0.5 mol% Tm: 2.5 mol%)	0.634	1.19	2.68
5-(30) $\text{CaAl}_2\text{O}_4\text{:Eu,Tm}$ (Eu: 0.5 mol% Tm: 10 mol%)	0.151	0.358	0.755

Table 13 shows the afterglow characteristics of phosphorescent phosphors which employ calcium, europium and either of lanthanum, cerium, praseodymium, gadolinium, terbium, holmium, erbium, ytterbium, lutetium, manganese, tin and bismuth as the metal element (M), the activator, and the co-activator, respectively, the phosphorescent phosphors being shown in 5-(31) to 5-(40).

0.5 mol% of europium as the activator and another co-activator were each doped to the phosphorescent phosphors shown in 5-(31) to 5-(40).

TABLE 13

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. CaSrS:Bi	1.00	1.00	1.00
(31) $\text{CaAl}_2\text{O}_4\text{:Eu,Lu}$ (Eu: 0.5 mol% Lu: 0.5 mol%)	0.52	0.67	0.81
(32) $\text{CaAl}_2\text{O}_4\text{:Eu,Ce}$ (Eu: 0.5 mol% Ce: 0.5 mol%)	0.84	1.23	1.96
(33) $\text{CaAl}_2\text{O}_4\text{:Eu,Pr}$ (Eu: 0.5 mol% Pr: 0.5 mol%)	0.58	0.82	1.13
(34) $\text{CaAl}_2\text{O}_4\text{:Eu,Gd}$ (Eu: 0.5 mol% Gd: 0.5 mol%)	0.66	0.91	1.26
(35) $\text{CaAl}_2\text{O}_4\text{:Eu,Ho}$ (Eu: 0.5 mol% Ho: 0.5 mol%)	0.98	1.33	2.39
(36) $\text{CaAl}_2\text{O}_4\text{:Eu,Er}$ (Eu: 0.5 mol% Er: 0.5 mol%)	0.56	0.76	0.98
(37) $\text{CaAl}_2\text{O}_4\text{:Eu,Yb}$ (Eu: 0.5 mol% Yb: 0.5 mol%)	0.70	0.91	1.28
(38) $\text{CaAl}_2\text{O}_4\text{:Eu,Lu}$ (Eu: 0.5 mol% Lu: 0.5 mol%)	0.68	0.90	1.24
(39) $\text{CaAl}_2\text{O}_4\text{:Eu,Sn}$ (Eu: 0.5 mol% Sn: 0.5 mol%)	0.45	0.58	0.73
(40) $\text{CaAl}_2\text{O}_4\text{:Eu,Bi}$ (Eu: 0.5 mol% Bi: 0.5 mol%)	0.25	0.33	0.48

#### Example 5 Synthesis of $\text{CaAl}_2\text{O}_4\text{:Eu, Nd}$ phosphorescent phosphor and characteristics thereof

Europium oxide ( $\text{Eu}_2\text{O}_3$ ) as an activator and neodymium as a co-activator were added to calcium carbonate having reagent grade and alumina having reagent grade and 5 g (0.08 mol) of boric acid was added thereto as flux.

Europium oxide ( $\text{Eu}_2\text{O}_3$ ) as an activator, neodymium as a co-activator, and further, either of lanthanum oxide, cerium oxide, praseodymium oxide, samarium oxide, gadolinium oxide, dysprosium oxide, holmium oxide, erbium oxide, thulium oxide, ytterbium oxide, lutetium oxide, tin oxide and bismuth oxide except neodymium oxide as another co-activator were doped to calcium carbonate having reagent grade and alumina having reagent grade and 5 g (0.08 mol) of boric acid was added thereto as flux. After the resultant mixture was sufficiently mixed using a ball mill, the sample was fired for 1 hour at 1300 °C in a stream of nitrogen-hydrogen mixture gas (97 : 3) (flow rate : 0.1 liter/min)

using an electric furnace. Thereafter, the sample was cooled to a room temperature for about 1 hour. The obtained powder compound was sieved having 100 mesh to obtain phosphorescent phosphor sample 6-(1) through 6-(41).

Various samples were manufactured with 0.5 mol% of Eu, 0.5 mol% of Nd and 0.5 mol% of another co-activator and the afterglow luminances 10 minutes, 30 minutes and 100 minutes after excitation were measured. Table 14 shows the results in 6-(1) through 6-(13).

TABLE 14

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. CaSrS:Bi	1.0	1.0	1.0
CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd	9.87	14.0	25.0
6-(1) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,La	20.6	23.2	29.5
(2) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Ce	12.7	17.5	26.9
(3) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Pr	13.3	18.1	27.7
(4) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Sm	8.20	12.6	22.6
(5) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Gd	16.7	21.3	33.5
(6) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Dy	14.8	18.9	30.8
(7) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Ho	16.9	21.6	34.3
(8) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Er	15.9	21.0	33.8
(9) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Tm	4.17	6.69	13.4
(10) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Yb	11.0	16.9	27.9
(11) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Lu	10.2	15.2	25.2
(12) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Sn	11.4	14.1	21.2
(13) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Bi	10.6	13.5	21.4

It was recognized from the result of the measurement that the co-activators doped together with neodymium which have a particularly excellent afterglow luminance, were lanthanum, dysprosium, gadolinium, holmium, erbium and the like.

Then, with 0.5 mol% of Eu and 0.5 mol% of Nd, the concentration of lanthanum was changed from 0.1 mol% to 10 mol%. Table 15 shows the result of the experiment in 6-(14) through 6-(19).

TABLE 15

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. CaSrS:Bi	1.0	1.0	1.0
(14) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd (Eu: 0.5 mol% Nd: 0.5 mol%)	9.87	14.0	25.0
(15) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,La (Eu: 0.5 mol% Nd: 0.5 mol% La: 0.1 mol%)	14.1	18.2	29.3
(16) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,La (Eu: 0.5 mol% Nd: 0.5 mol% La: 0.3 mol%)	15.5	18.9	28.5

Continuation of the Table on the next page

TABLE 15 (continued)

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
(1) $\text{CaAl}_2\text{O}_4\text{:Eu,Nd,La}$ (Eu: 0.5 mol% Nd: 0.5 mol% La: 0.5 mol%)	20.6	23.2	29.5
(17) $\text{CaAl}_2\text{O}_4\text{:Eu,Nd,La}$ (Eu: 0.5 mol% Nd: 0.5 mol% La: 1.0 mol%)	1.42	1.05	0.858
(18) $\text{CaAl}_2\text{O}_4\text{:Eu,Nd,La}$ (Eu: 0.5 mol% Nd: 0.5 mol% La: 2.0 mol%)	Measurement Limit		
(19) $\text{CaAl}_2\text{O}_4\text{:Eu,Nd,La}$ (Eu: 0.5 mol% Nd: 0.5 mol% La: 10 mol%)	Measurement Limit		

With 0.5 mol% of Eu and 0.5 mol% of Nd, the concentration of dysprosium was changed from 0.1 mol% to 10 mol%. Table 16 shows the result of the experiment in 6-(20) through 6-(25).

TABLE 16

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. $\text{CaSrS:Bi}$	1.0	1.0	1.0
(20) $\text{CaAl}_2\text{O}_4\text{:Eu,Nd}$ (Eu: 0.5 mol% Nd: 0.5 mol%)	9.87	14.0	25.0
(21) $\text{CaAl}_2\text{O}_4\text{:Eu,Nd,Dy}$ (Eu: 0.5 mol% Nd: 0.5 mol% Dy: 0.1 mol%)	4.32	6.76	12.0
(22) $\text{CaAl}_2\text{O}_4\text{:Eu,Nd,Dy}$ (Eu: 0.5 mol% Nd: 0.5 mol% Dy: 0.3 mol%)	8.91	14.0	24.2
(6) $\text{CaAl}_2\text{O}_4\text{:Eu,Nd,Dy}$ (Eu: 0.5 mol% Nd: 0.5 mol% Dy: 0.5 mol%)	14.8	18.9	30.8
(23) $\text{CaAl}_2\text{O}_4\text{:Eu,Nd,Dy}$ (Eu: 0.5 mol% Nd: 0.5 mol% Dy: 1.0 mol%)	12.1	18.3	27.8
(24) $\text{CaAl}_2\text{O}_4\text{:Eu,Nd,Dy}$ (Eu: 0.5 mol% Nd: 0.5 mol% Dy: 2.0 mol%)	7.49	10.3	16.0
(25) $\text{CaAl}_2\text{O}_4\text{:Eu,Nd,Dy}$ (Eu: 0.5 mol% Nd: 0.5 mol% Dy: 10 mol%)	1.84	1.29	0.998

With 0.5 mol% of Eu and 0.5 mol% of Nd, the concentration of gadolinium was changed from 0.1 mol% to 10 mol%. Table 17 shows the result of the experiment in 6-(26) through 6-(30).

TABLE 17

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. CaSrS:Bi	1.0	1.0	1.0
CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd (Eu: 0.5 mol% Nd: 0.5 mol%)	9.87	14.0	25.0
(26) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Gd (Eu: 0.5 mol% Nd: 0.5 mol% Gd: 0.1 mol%)	11.8	17.4	30.0
(27) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Gd (Eu: 0.5 mol% Nd: 0.5 mol% Gd: 0.3 mol%)	12.7	17.8	29.8
(5) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Gd (Eu: 0.5 mol% Nd: 0.5 mol% Gd: 0.5 mol%)	16.7	21.3	33.5
(28) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Gd (Eu: 0.5 mol% Nd: 0.5 mol% Gd: 1.0 mol%)	10.8	15.7	26.5
(29) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Gd (Eu: 0.5 mol% Nd: 0.5 mol% Gd: 2.0 mol%)	18.0	21.7	29.5
(30) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Gd (Eu: 0.5 mol% Nd: 0.5 mol% Gd: 10 mol%)	1.01	0.764	0.590

With 0.5 mol% of Eu and 0.5 mol% of Nd, the concentration of holmium was changed from 0.1- mol% to 10 mol%. Table 18 shows the result of the experiment in 6-(31) through 6-(35).

TABLE 18

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. CaSrS:Bi	1.0	1.0	1.0
CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd (Eu: 0.5 mol% Nd: 0.5 mol%)	9.87	14.0	25.0
(31) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Ho (Eu: 0.5 mol% Nd: 0.5 mol% Ho: 0.1 mol%)	10.4	14.4	25.3
(32) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Ho (Eu: 0.5 mol% Nd: 0.5 mol% Ho: 0.3 mol%)	12.0	16.2	27.0
(7) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Ho (Eu: 0.5 mol% Nd: 0.5 mol% Ho: 0.5 mol%)	16.5	21.6	34.3
(33) CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd,Ho (Eu: 0.5 mol% Nd: 0.5 mol% Ho: 1.0 mol%)	13.4	16.9	26.3

Continuation of the Table on the next page

TABLE 18 (continued)

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
(34) $\text{CaAl}_2\text{O}_4:\text{Eu,Nd,Ho}$ (Eu: 0.5 mol% Nd: 0.5 mol% Ho: 2.0 mol%)	13.3	16.0	23.5
(35) $\text{CaAl}_2\text{O}_4:\text{Eu,Nd,Ho}$ (Eu: 0.5 mol% Nd: 0.5 mol% Ho: 10 mol%)	1.20	0.914	0.782

With 0.5 mol% of Eu and 0.5 mol% of Nd, the concentration of erbium was changed from 0.1 mol% to 5 mol%. Table 19 shows the result of the experiment in 6-(36) through 6-(41).

TABLE 19

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. $\text{CaSrS:Bi}$	1.0	1.0	1.0
$\text{CaAl}_2\text{O}_4:\text{Eu,Nd}$ (Eu: 0.5 mol% Nd: 0.5 mol%)	9.87	14.0	25.0
(36) $\text{CaAl}_2\text{O}_4:\text{Eu,Nd,Er}$ (Eu: 0.5 mol% Nd: 0.5 mol% Er: 0.1 mol%)	10.7	15.1	27.0
(37) $\text{CaAl}_2\text{O}_4:\text{Eu,Nd,Er}$ (Eu: 0.5 mol% Nd: 0.5 mol% Er: 0.3 mol%)	10.3	14.0	24.0
(8) $\text{CaAl}_2\text{O}_4:\text{Eu,Nd,Er}$ (Eu: 0.5 mol% Nd: 0.5 mol% Er: 0.5 mol%)	15.9	21.0	33.8
(38) $\text{CaAl}_2\text{O}_4:\text{Eu,Nd,Er}$ (Eu: 0.5 mol% Nd: 0.5 mol% Er: 1.0 mol%)	16.4	21.1	32.3
(39) $\text{CaAl}_2\text{O}_4:\text{Eu,Nd,Er}$ (Eu: 0.5 mol% Nd: 0.5 mol% Er: 2.0 mol%)	17.3	21.7	30.8
(40) $\text{CaAl}_2\text{O}_4:\text{Eu,Nd,Er}$ (Eu: 0.5 mol% Nd: 0.5 mol% Er: 3.0 mol%)	20.1	21.3	28.5
(41) $\text{CaAl}_2\text{O}_4:\text{Eu,Nd,Er}$ (Eu: 0.5 mol% Nd: 0.5 mol% Er: 5.0 mol%)	17.5	17.8	22.0

It was recognized from the results of the measurements that certain mixtures of the co-activators improved the afterglow luminance. Further, it was also recognized that the sample had the most excellent afterglow characteristics when, with 0.5 mol% of Eu and 0.5 mol% of Nd, about 0.5 mol% of another co-activator was added.

#### Example 6 $\text{BaAl}_2\text{O}_4$ : Eu phosphorescent phosphor

After 0.5 mol% of Eu was added to the phosphorescent phosphor, further 0.5 mol% of Nd or Sm was added thereto. The results are shown in 7-(1) and 7-(2).

Fig. 13 shows the excitation spectrum of the phosphorescent phosphor which employs neodymium as the co-



activator and the afterglow emission spectrum thereof obtained 30 minutes after excitation is ceased.

Fig. 14 shows the excitation spectrum of the phosphorescent phosphor which employs samarium as the co-activator and the afterglow emission spectrum thereof obtained 30 minutes after excitation is ceased.

The peak wavelength of emission spectrum is always about 500 nm, the emission spectrum emitting light of green. Table 20 shows the results of the comparison between the afterglow characteristics of the obtained  $\text{BaAl}_2\text{O}_4$  : Eu phosphorescent phosphor and those of ZnS : Cu phosphorescent phosphor which is available on the market and which emits light of green (manufactured by Nemoto & Co., LTD : GSS, and the wavelength of emission peak : 530 nm), indicating relative values of the afterglow intensities 10 minutes, 30 minutes and 100 minutes after excitation is ceased.

TABLE 20

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. ZnS:Cu	1.0	1.0	1.0
$\text{BaAl}_2\text{O}_4$ :Eu,Nd (Eu: 0.5 mol% Nd: 0.5 mol%)	1.23	1.14	0.885
$\text{BaAl}_2\text{O}_4$ :Eu,Sm (Eu: 0.5 mol% Sm: 0.5 mol%)	0.982	0.911	0.768

Table 20 shows that  $\text{BaAl}_2\text{O}_4$  : Eu, Nd has a more excellent afterglow luminance than ZnS : Cu phosphorescent phosphor for about 30 minutes after excitation is ceased. It was found that  $\text{BaAl}_2\text{O}_4$  : Eu, Sm had a little lower afterglow luminance than ZnS : Cu phosphorescent phosphor. However, it has been confirmed that no fluorescence or afterglow is recognized as a result of experiments with only  $\text{BaAl}_2\text{O}_4$  crystal without adding Eu or other co-activator thereto. Therefore, it is evident that the effects of activation can be assured by doping Eu, Nd or Sm to  $\text{BaAl}_2\text{O}_4$  phosphorescent phosphor.

Since  $\text{BaAl}_2\text{O}_4$  : Eu phosphorescent phosphor is an oxide, it is chemically stable and shows excellent photo-resistance when compared with conventional sulfide phosphorescent phosphors (see Tables 24, 25).

#### Example 7 Synthesis of $\text{SrxCa}_{1-x}\text{Al}_2\text{O}_4$ phosphorescent phosphor and characteristics thereof

Strontium carbonate having reagent grade and calcium carbonate having reagent grade were mixed with each other at different ratios. Alumina was added to each of the obtained samples. Also, europium and either of lanthanum, cerium, praseodymium, neodymium, samarium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, manganese, tin and bismuth were added to each of the samples as the activator and the co-activator, respectively, and additionally, 5 g (0.08 mol) of boric acid was added thereto as flux to obtain  $\text{SrxCa}_{1-x}\text{Al}_2\text{O}_4$  phosphorescent phosphor samples in the manner described above.

Fig. 15 shows the results of the examination of the afterglow emission spectrum of  $\text{Sr0.5Ca0.5Al}_2\text{O}_4$  : Eu, Dy phosphorescent phosphor (Eu 0.5 mol%, Dy 0.5 mol%). It is apparent from Fig. 15 that when Ca is substituted for a part of Sr, the emission wavelength is reduced and thus produces an afterglow having a color between that obtained by emission of  $\text{SrAl}_2\text{O}_4$  phosphorescent phosphor and that obtained by emission of  $\text{CaAl}_2\text{O}_4$  phosphorescent phosphor.

Fig. 16 shows the results of the examination of the afterglow characteristics of  $\text{SrxCa}_{1-x}\text{Al}_2\text{O}_4$  phosphorescent phosphor samples in which 0.5 mol% of Eu and 0.5 mol% of Dy were added as the activator and the co-activator, respectively.

As can be seen from Fig. 16, any of these phosphorescent phosphors shows excellent afterglow characteristics and is thus practically applicable as compared with the currently available phosphorescent phosphors shown by the broken line in Fig. 16.

#### Example 8 Synthesis of $\text{SrxBa}_{1-x}\text{Al}_2\text{O}_4$ phosphorescent phosphor and characteristics thereof

Strontium carbonate having reagent grade and barium carbonate having reagent grade were mixed with each other at different ratios. Alumina was added to each of the obtained samples. Also, europium and either of lanthanum, cerium, praseodymium, neodymium, samarium, gadolinium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, tin and bismuth were added to each of the samples as the activator and the co-activator, respectively, and 5 g (0.08 mol) of boric acid was added thereto as flux to obtain  $\text{SrxBa}_{1-x}\text{Al}_2\text{O}_4$  phosphorescent phosphor samples in the manner described above.

Fig. 17 shows the results of the examination of the afterglow characteristics of  $\text{SrXBa}_{1-x}\text{Al}_2\text{O}_4$  phosphorescent phosphors to which 0.5 mol% of Eu and 0.5 mol% of Dy were added.

As can be seen from Fig. 17, any of these phosphorescent phosphors shows excellent afterglow characteristics and is thus practically applicable as compared with the currently available phosphorescent phosphor shown by the broken line in Fig. 17.

#### Example 9 Synthesis of $\text{SrXMg}_{1-x}\text{Al}_2\text{O}_4$ phosphorescent phosphor and characteristics thereof

Strontium carbonate having reagent grade and magnesium carbonate having reagent grade were mixed with each other at different ratios. Alumina was added to each of the obtained samples. Also, europium and either of lanthanum, cerium, praseodymium, neodymium, samarium, gadolinium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, tin, and bismuth were added to each of the samples as the activator and the co-activator, respectively, and additionally, 5 g (0.08 mol) of boric acid was added thereto as flux to obtain  $\text{SrXMg}_{1-x}\text{Al}_2\text{O}_4$  phosphorescent phosphor samples in the manner described above. Fig. 18 shows the results of the examination of the afterglow characteristics of  $\text{SrXMg}_{1-x}\text{Al}_2\text{O}_4$  phosphorescent phosphors to which 0.5 mol% of Eu and 0.5 mol% of Dy were added.

As can be seen from Fig. 18, any of these phosphorescent phosphors shows excellent afterglow characteristics and is thus practically applicable except for the phosphorescent phosphors in which the ratio between strontium and magnesium was 0.1/0.9, as compared with the currently available phosphorescent phosphor shown by the broken line in Fig. 18.

#### Example 10 Synthesis of $\text{Ca}_{1-x}\text{SrXAl}_2\text{O}_4$ : Eu, Nd, X phosphorescent phosphor and characteristics thereof

Strontium carbonate having reagent grade and calcium carbonate having reagent grade were mixed with each other at different ratios. Alumina was added to each of the obtained samples. Also, 0.5 mol% of europium, 0.5 mol% of neodymium and further, 0.5 mol% of either of lanthanum, dysprosium and holmium were added to each of the samples as the activator, the co-activator and another co-activator, respectively, and 5 g (0.08 mol) of boric acid was added thereto as flux to obtain  $\text{Ca}_{1-x}\text{SrXAl}_2\text{O}_4$  : Eu, Nd, X phosphorescent phosphor samples 11-(1) through 11-(9) in the manner described above. Then, the afterglow characteristics of the samples were examined.

Strontium carbonate having reagent grade and calcium carbonate having reagent grade were mixed with each other at different ratios. Alumina was added to each of the obtained samples. Also, 0.5 mol% of europium, 0.5 mol% of neodymium and further, 0.5 mol% of lanthanum were added to each of the samples as the activator, the co-activator and another co-activator, respectively, to obtain the samples 11-(1) through 11-(3) shown in Table 21.

TABLE 21

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. $\text{CaSrS:Bi}$	1.0	1.0	1.0
$\text{CaAl}_2\text{O}_4\text{:Eu,Nd}$	9.87	14.0	25.0
11-(1) ( $\text{Ca}_{0.9}\text{Sr}_{0.1}$ ) $\text{Al}_2\text{O}_4\text{:Eu,Nd,La}$	15.2	17.1	19.0
(2) ( $\text{Ca}_{0.7}\text{Sr}_{0.3}$ ) $\text{Al}_2\text{O}_4\text{:Eu,Nd,La}$	5.53	4.96	3.35
(3) ( $\text{Ca}_{0.5}\text{Sr}_{0.5}$ ) $\text{Al}_2\text{O}_4\text{:Eu,Nd,La}$	6.30	3.08	Measurement limit

Strontium carbonate having reagent grade and calcium carbonate having reagent grade were mixed with each other at different ratios. Alumina was added to each of the obtained samples. Also, 0.5 mol% of europium, 0.5 mol% of neodymium and further, 0.5 mol% of dysprosium were added to each of the samples as the activator, the co-activator and another co-activator, respectively, to obtain the samples 11-(4) through 11-(6) shown in Table 22.

TABLE 22

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. CaSrS:Bi	1.0	1.0	1.0
CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd	9.87	14.0	25.0
(4) (Ca <sub>0.9</sub> Sr <sub>0.1</sub> )Al <sub>2</sub> O <sub>4</sub> :Eu, Nd,Dy	13.2	14.6	20.4
(5) (Ca <sub>0.7</sub> Sr <sub>0.3</sub> )Al <sub>2</sub> O <sub>4</sub> :Eu, Nd,Dy	8.00	7.46	9.05
(6) (Ca <sub>0.5</sub> Sr <sub>0.5</sub> )Al <sub>2</sub> O <sub>4</sub> :Eu, Nd,Dy	3.36	3.08	Measurement limit

Strontium carbonate having reagent grade and calcium carbonate having reagent grade were mixed with each other at different ratios. Alumina was added to each of the obtained samples. Also, 0.5 mol% of europium, 0.5 mol% of neodymium and further, 0.5 mol% of holmium were added to each of the samples as the activator, the co-activator and another co-activator, respectively, to obtain the samples 11-(7) through 11-(9) shown in Table 23.

TABLE 23

Sample	Luminance 10 minutes after	Luminance 30 minutes after	Luminance 100 minutes after
Std. CaSrS:Bi	1.0	1.0	1.0
CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd	9.87	14.0	25.0
(7) (Ca <sub>0.9</sub> Sr <sub>0.1</sub> )Al <sub>2</sub> O <sub>4</sub> :Eu, Nd,Ho	13.9	15.3	21.4
(8) (Ca <sub>0.7</sub> Sr <sub>0.3</sub> )Al <sub>2</sub> O <sub>4</sub> :Eu, Nd,Ho	8.25	7.81	9.95
(9) (Ca <sub>0.5</sub> Sr <sub>0.5</sub> )Al <sub>2</sub> O <sub>4</sub> :Eu, Nd,Ho	2.91	2.62	3.65

As can be seen from the results of the measurement, the phosphorescent phosphors which employ calcium and strontium as the metal element (M), employ europium as the activator and employ a plurality of co-activators shows excellent afterglow characteristics than CaSrS: Bi and further the luminance 10 minutes after excitation was more excellent than CaSrS: Bi.

#### Example 11 Humidity test

Table 24 shows the results of the examination of moisture resistance characteristics of phosphorescent phosphor obtained according to the present invention.

In the humidity test, a plurality of phosphorescent phosphor samples were left for 500 hours in a constant temperature and humidity bath which was adjusted to 40°C and 95%RH, and the resultant changes in the luminance of each of the samples were measured.

As can be seen from Table 24, none of the samples was affected by humidity and the samples were thus stable.

TABLE 24

Sample	Before test	After test
SrAl <sub>2</sub> O <sub>4</sub> :Eu,Dy (Eu: 0.5 mol% Dy: 0.5 mol%)	1.0	1.01
CaAl <sub>2</sub> O <sub>4</sub> :Eu,Nd (Eu: 0.5 mol% Nd: 0.5 mol%)	1.0	0.99

Continuation of the Table on the next page

6. Matière luminescente selon la revendication 5, dans laquelle la teneur totale en coactivateur est 0,001 à 10 % en moles par rapport au métal ou aux métaux dans la matrice.
- 5 7. Matière luminescente selon l'une quelconque des revendications précédentes qui présente un pic luminescent de thermoluminescence dans une région haute température de 50 °C ou plus lorsqu'elle est irradiée par des rayons ultraviolets ou visibles ayant une longueur d'onde de 200 à 450 nm à des températures ambiantes.
- 10 8. Composition qui comprend une matière luminescente selon l'une quelconque des revendications 1 à 7 mélangée avec une matière plastique, un caoutchouc, du verre ou une encre.
- 15 9. Procédé pour conférer des caractéristiques de luminescence résiduelle à un substrat choisi parmi une jauge, un cadran de réveil, un panneau de sécurité, un véhicule, une clé, un trou de serrure, un panneau de signalisation routière, une barrière de sécurité, une bouée de pêche, un casque, un poteau indicateur, un commutateur électrique, un instrument d'écriture, une carte, un jouet ou une balle de sport, ce procédé comprenant l'application, sur ledit substrat, d'une matière luminescente telle que revendiquée dans l'une quelconque des revendications 1 à 7.
- 20
- 25
- 30
- 35
- 40
- 45
- 50
- 55

TABLE 24 (continued)

Sample	Before test	After test
$\text{Sr}_{0.5}\text{Ca}_{0.5}\text{Al}_2\text{O}_4:\text{Eu,Dy}$ (Eu: 0.5 mol% Dy: 0.5 mol%)	1.0	1.00
$\text{Sr}_{0.5}\text{Ba}_{0.5}\text{Al}_2\text{O}_4:\text{Eu,Dy}$ (Eu: 0.5 mol% Dy: 0.5 mol%)	1.0	0.99
$\text{Sr}_{0.5}\text{Mg}_{0.5}\text{Al}_2\text{O}_4:\text{Eu,Dy}$ (Eu: 0.5 mol% Dy: 0.5 mol%)	1.0	1.02

**Example 12 Photo resistance test**

Fig. 25 shows the results of the photo resistance test conducted on the phosphorescent phosphors according to the present invention together with the results obtained from zinc sulfide phosphorescent phosphor.

This test was conducted conforming to JIS standard on the sample placed in a transparent container whose humidity was adjusted to saturated humidity by irradiating the sample by a mercury lamp of 300 W located at 30 cm above the sample for 3 hours, 6 hours and 12 hours, respectively, and by measuring changes in the luminance caused by irradiation.

As can be seen from Table 25, phosphorescent phosphors according to the present invention are very stable as compared with conventional zinc sulfide phosphorescent phosphor.

TABLE 25

Sample	Before test	3 hours after	6 hours after	12 hours after
Std. ZnS:Cu	1.0	0.91	0.82	0.52
$\text{SrAl}_2\text{O}_4:\text{Eu,Dy}$ (Eu: 0.5 mol% Dy: 0.5 mol%)	1.0	1.01	1.00	1.01
$\text{CaAl}_2\text{O}_4:\text{Eu,Nd}$ (Eu: 0.5 mol% Nd: 0.5 mol%)	1.0	1.00	1.01	1.00
$\text{Sr}_{0.5}\text{Ca}_{0.5}\text{Al}_2\text{O}_4:\text{Eu,Dy}$ (Eu: 0.5 mol% Dy: 0.5 mol%)	1.0	1.00	0.99	1.00
$\text{Sr}_{0.5}\text{Ba}_{0.5}\text{Al}_2\text{O}_4:\text{Eu,Dy}$ (Eu: 0.5 mol% Dy: 0.5 mol%)	1.0	1.01	1.01	1.01
$\text{Sr}_{0.5}\text{Mg}_{0.5}\text{Al}_2\text{O}_4:\text{Eu,Dy}$ (Eu: 0.5 mol% Dy: 0.5 mol%)	1.0	1.00	1.00	0.99

For use, phosphorescent phosphor according to the present invention may be coated on the surface of any of various products. It may also be mixed into a plastic material, rubber or glass.

Also, phosphorescent phosphor according to the present invention may replace conventional sulfide phosphorescent phosphors. The phosphorescent phosphor according to the present invention will show excellent characteristics in applying it to various gauges, dial plates of clocks, and safety signs, due to the long-lasting high-luminance afterglow characteristics thereof.

The phosphorescent phosphor according to the present invention can be employed in any of the following applications, because it has excellent long-lasting high-luminance afterglow characteristics and because it is an oxide and hence chemically stable and shows excellent photo-resistance.

Indicator for vehicles :	airplane, ship, automobile, bicycle, key, key hole
Indicator for signs :	traffic sign, indicator of traffic lanes, indicator for a guard rail, fishing buoy, direction board on a maintain trail, direction board which guides a guest from a gate to a front door, indication on helmet
Outdoor indicator :	signboard, indicator for buildings, indicator for the key hole of automobile,
Indoor indicator :	electrical appliance switches
Stationery :	writing instruments, luminous ink, map, star chart
Toys :	Jigsaw puzzle

Special usage : sports ball, back-light for liquid-crystal (for use in, for example, clock), replacement of isotope used for discharge tube

As described above, the present invention relates to a novel phosphorescent phosphor which is completely different from well-known sulfide phosphorescent phosphors, and has much longer high-luminance afterglow characteristics as compared with sulfide phosphorescent phosphors which are available on the market. Further, the phosphorescent phosphor according to the present invention is chemically stable because it is an oxide and has excellent photo-resistance.

## Claims

1. A phosphor which comprises a matrix of formula  $MAI_2O_4$  wherein M is calcium, strontium or barium, the matrix comprising europium as activator and, as co-activator, at least one element selected from lanthanum, cerium, praseodymium, neodymium, samarium, gadolinium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, tin and bismuth.
2. A phosphor comprising a matrix of formula  $MAI_2O_4$  wherein M comprises at least two metals selected from calcium, strontium, barium and magnesium, the matrix comprising europium as activator and, as co-activator at least one element selected from lanthanum, cerium, praseodymium, neodymium, samarium, gadolinium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, tin and bismuth.
3. A phosphor comprising a matrix of formula  $(M'_xM''_y)Al_2O_4$  wherein  $x + y = 1$  and  $M'$  and  $M''$ , which are different, are each a metal selected from calcium, barium, strontium and magnesium, the matrix comprising europium as activator and, as co-activator, at least one element selected from lanthanum, cerium, praseodymium, neodymium, samarium, gadolinium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, tin and bismuth.
4. A phosphor according to any one of claims 1 to 3 wherein the matrix comprises europium in an amount of 0.001 to 10 mol% relative to the metal or metals in the matrix.
5. A phosphor according to any one of claims 1 to 3 which comprises the co-activator or each co-activator in an amount of 0.001 to 10 mol % relative to the metal or metals in the matrix.
6. A phosphor according to claim 5 wherein the total amount of co-activator is 0.001 to 10 mol% relative to the metal or metals in the matrix.
7. A phosphor according to any one of the preceding claims which shows a glow peak of thermo-luminescence in a high temperature region of 50°C or above when irradiated by ultraviolet or visible rays having a wavelength of 200 to 450 nm at room temperatures.
8. A composition which comprises a phosphor as claimed in any one of claims 1 to 7 mixed with a plastic material, rubber, glass or ink.
9. A method of imparting afterglow characteristics to a substrate selected from a gauge, clock dial, safety sign, vehicle, key, key-hole, traffic sign, guard rail, fishing buoy, helmet, signpost, electrical switch, writing instrument, map, toy or sportsball, which method comprising applying to the said substrate a phosphor as claimed in any one of claims 1 to 7.

## Patentansprüche

1. Phosphor mit einer Matrix der Formel  $MAI_2O_4$ , in welcher M Calcium, Strontium oder Barium ist, wobei die Matrix Europium als Aktivator aufweist und als Co-Aktivator zumindest ein Element aus der folgenden Gruppe: Lanthan, Cer, Praseodym, Neodym, Samarium, Gadolin, Dysprosium, Holmium, Erbium, Thulium, Ytterbium, Lutetium, Zinn und Wismut.
2. Phosphor mit einer Matrix der Formel  $MAI_2O_4$ , in welcher M zumindest zwei Metalle aus der Gruppe Calcium, Strontium, Barium und Magnesium aufweist und die Matrix als Aktivator Europium umfaßt und als Co-Aktivator

zumindest ein Element aus der folgenden Gruppe: Lanthan, Cer, Praseodym, Neodym, Samarium, Gadolin, Dysprosium, Holmium, Erbium, Thulium, Ytterbium, Lutetium, Zinn und Wismut.

- 5 3. Phosphor mit einer Matrix der Formel  $(M'_x M''_y) Al_2 O_4$ , in welcher  $x + y = 1$  und  $M'$  und  $M''$ , die sich voneinander unterscheiden, jeweils ein Metall aus der Gruppe: Calcium, Barium, Strontium und Magnesium sind, wobei die Matrix Europium als Aktivator umfaßt und als Co-Aktivator zumindest ein Element aus der folgenden Gruppe: Lanthan, Cer, Praseodym, Neodym, Samarium, Gadolin, Dysprosium, Holmium, Erbium, Thulium, Ytterbium, Lutetium, Zinn und Wismut.
- 10 4. Phosphor nach einem der Ansprüche 1 bis 3, in welchem die Matrix Europium zu einem Anteil von 0,001 bis 10 mol% im Verhältnis zum Metall oder den Metallen in der Matrix aufweist.
- 5 5. Phosphor nach einem der Ansprüche 1 bis 3, das den Co-Aktivator oder jeden Co-Aktivator zu einem Anteil von 0,001 bis 10 mol% im Verhältnis zum Metall oder den Metallen in der Matrix aufweist.
- 15 6. Phosphor nach Anspruch 5, in welchem der Gesamtanteil der Co-Aktivatoren 0,001 bis 10 mol% im Verhältnis zum Metall oder den Metallen in der Matrix ist.
- 20 7. Phosphor nach einem der vorangehenden Ansprüche, das ein Thermolumineszenzleuchtmaximum in einem Hochtemperaturbereich von 50°C oder darüber aufweist, wenn es mit ultravioletten oder sichtbaren Strahlen mit einer Wellenlänge von 200 bis 450 nm bei Raumtemperatur bestrahlt wird.
- 25 8. Zusammensetzung, die Phosphor nach einem der Ansprüche 1 bis 7 aufweist, das mit Kunststoff, Gummi, Glas oder Tinte vermischt ist.
- 30 9. Verfahren, um einem Substrat Nachleuchteigenschaften zu verleihen, wobei das Substrat bei folgenden Gegenständen eingesetzt wird: einem Meßinstrument, einem Ziffernblatt, einem Sicherheitszeichen, einem Fahrzeug, einem Schlüssel, einem Schlüsselloch, einem Verkehrszeichen, einem Schutzgelenker, einer Fischerboje, einem Helm, einem Markierungsposten, einem elektrischen Schalter, einem Schreibinstrument, einer Karte, einem Spielzeug oder einem Sportball, wobei das Verfahren beinhaltet, daß dem Substrat Phosphor gemäß einem der Ansprüche 1 bis 7 beigemischt wird.

#### Revendications

- 35 1. Matière luminescente qui comprend une matrice de formule  $MAI_2 O_4$  où M est le calcium, le strontium ou le baryum, la matrice comprenant de l'euporium en tant qu'activateur et, en tant que coactivateur, au moins un élément choisi parmi le lanthane, le cérium, le praséodyme, le néodyme, le samarium, le gadolinium, le dysprosium, l'holmium, l'erbium, le thulium, l'ytterbium, le lutétium, l'étain et le bismuth.
- 40 2. Matière luminescente comprenant une matrice de formule  $MAI_2 O_4$  où M comprend au moins deux métaux choisis parmi le calcium, le strontium, le baryum et le magnésium, la matrice comprenant de l'euporium en tant qu'activateur et, en tant que coactivateur, au moins un élément choisi parmi le lanthane, le cérium, le praséodyme, le néodyme, le samarium, le gadolinium, le dysprosium, l'holmium, l'erbium, le thulium, l'ytterbium, le lutétium, l'étain et le bismuth.
- 45 3. Matière luminescente comprenant une matrice de formule  $(M'_x M''_y) Al_2 O_4$  où  $x + y = 1$  et  $M'$  et  $M''$ , qui sont différents, sont chacun un métal choisi parmi le calcium, le baryum, le strontium et le magnésium, la matrice comprenant de l'euporium en tant qu'activateur et, en tant de coactivateur, au moins un élément choisi parmi le lanthane, le cérium, le praséodyme, le néodyme, le samarium, le gadolinium, le dysprosium, l'holmium, l'erbium, le thulium, l'ytterbium, le lutétium, l'étain et le bismuth.
- 50 4. Matière luminescente selon l'une quelconque des revendications 1 à 3, dans laquelle la matrice comprend de l'euporium en une teneur de 0,001 à 10 % en moles par rapport au métal ou aux métaux dans la matrice.
- 55 5. Matière luminescente selon l'une quelconque des revendications 1 à 3, qui comprend le coactivateur ou chaque coactivateur en une teneur de 0,001 à 10 % en moles par rapport au métal ou aux métaux dans la matrice.

Fig.1

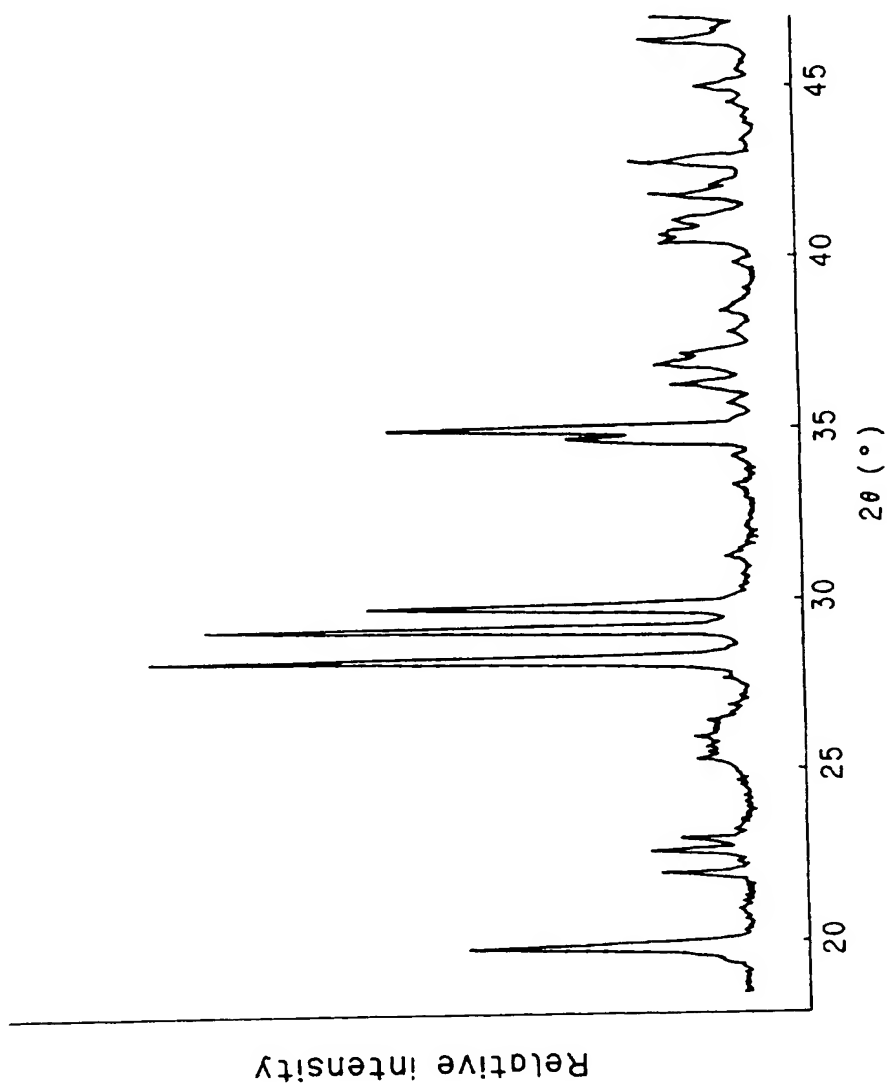




Fig.2

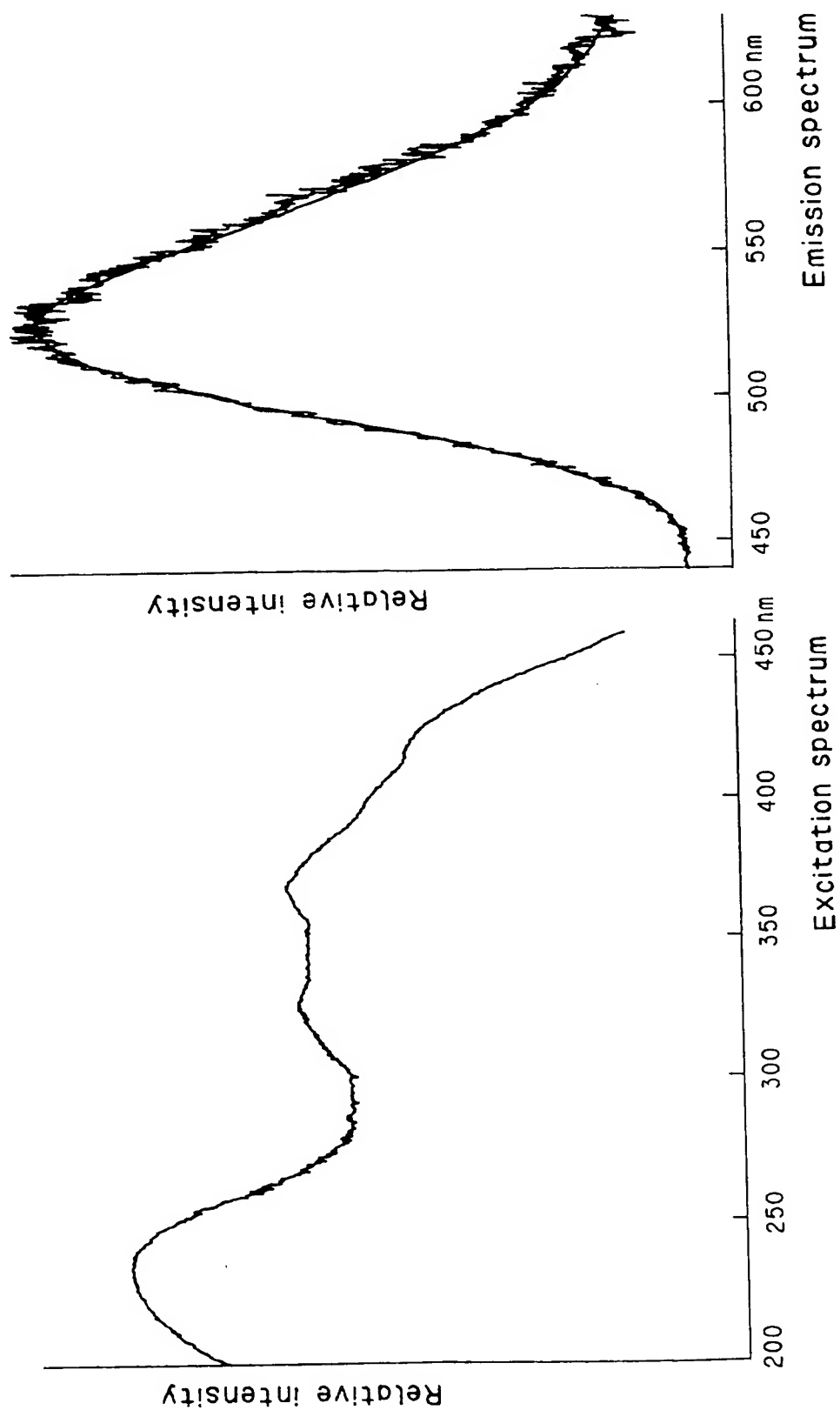
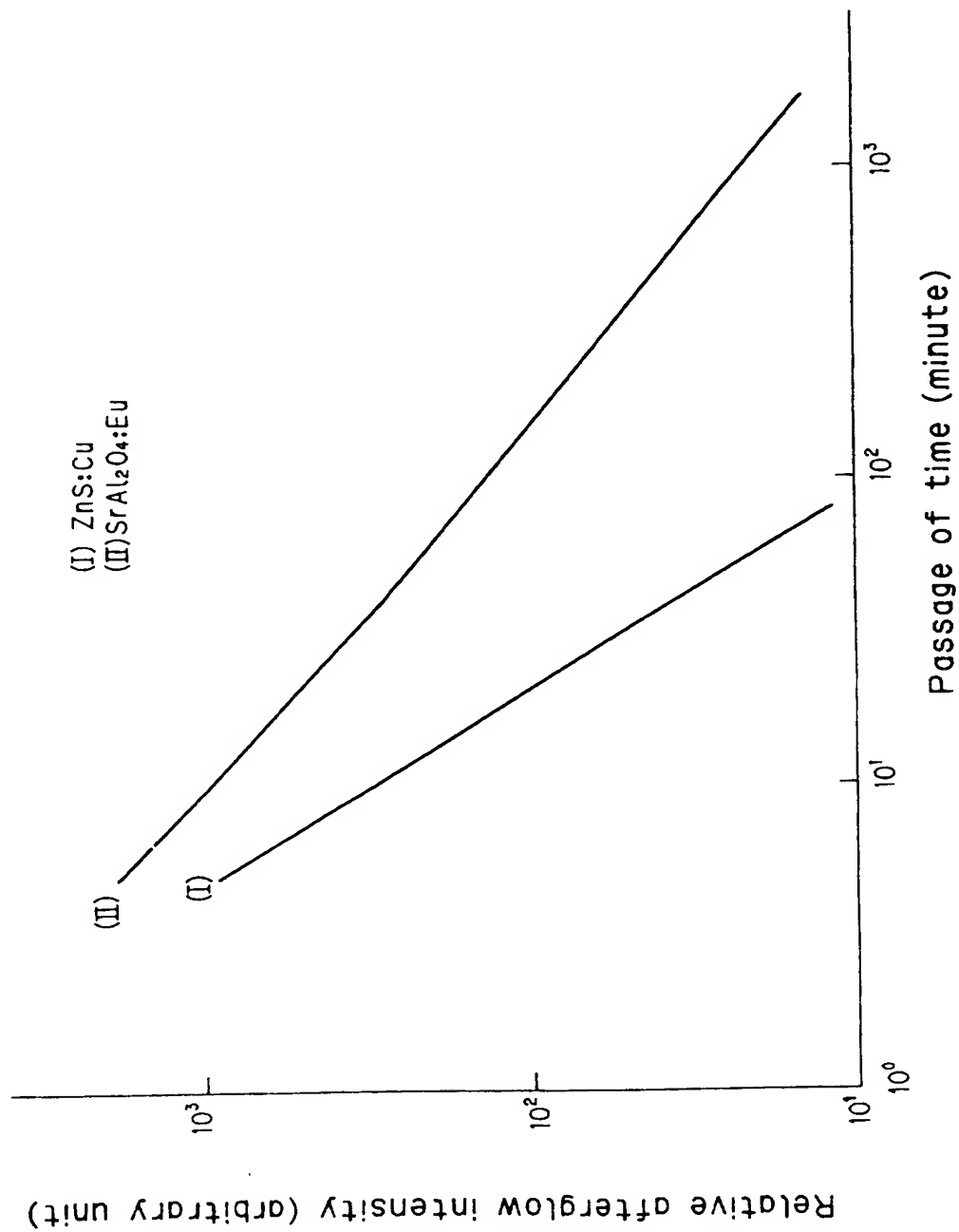


Fig.3



**Fig.4**

- (I) 20 seconds after irradiation of D65 standard light for 2 seconds  
(II) 20 seconds after irradiation of D65 standard light for 4 seconds  
(III) 20 seconds after irradiation of D65 standard light for 8 seconds  
(IV) 20 seconds after irradiation of D65 standard light for 20 seconds

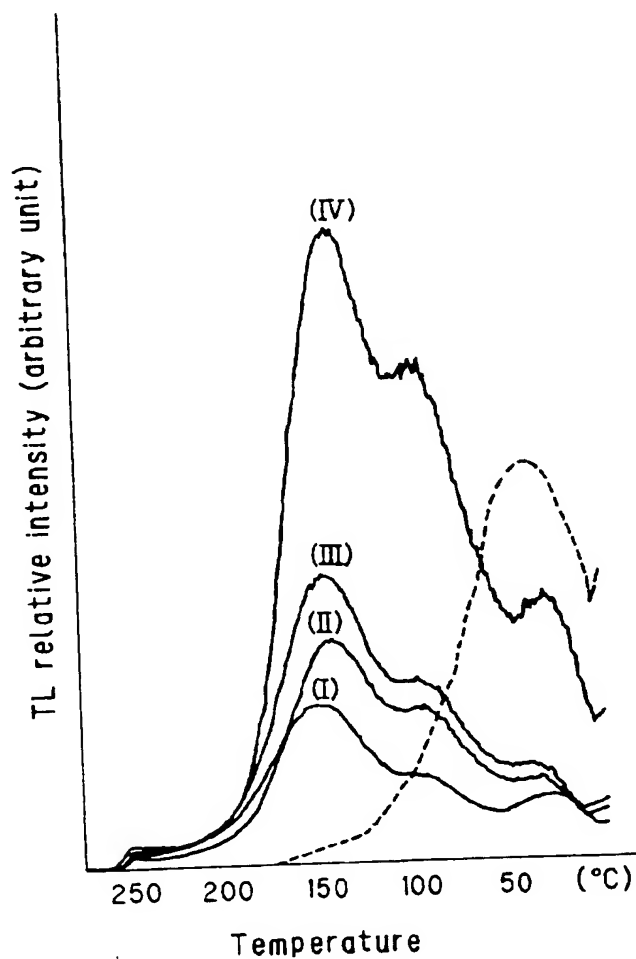
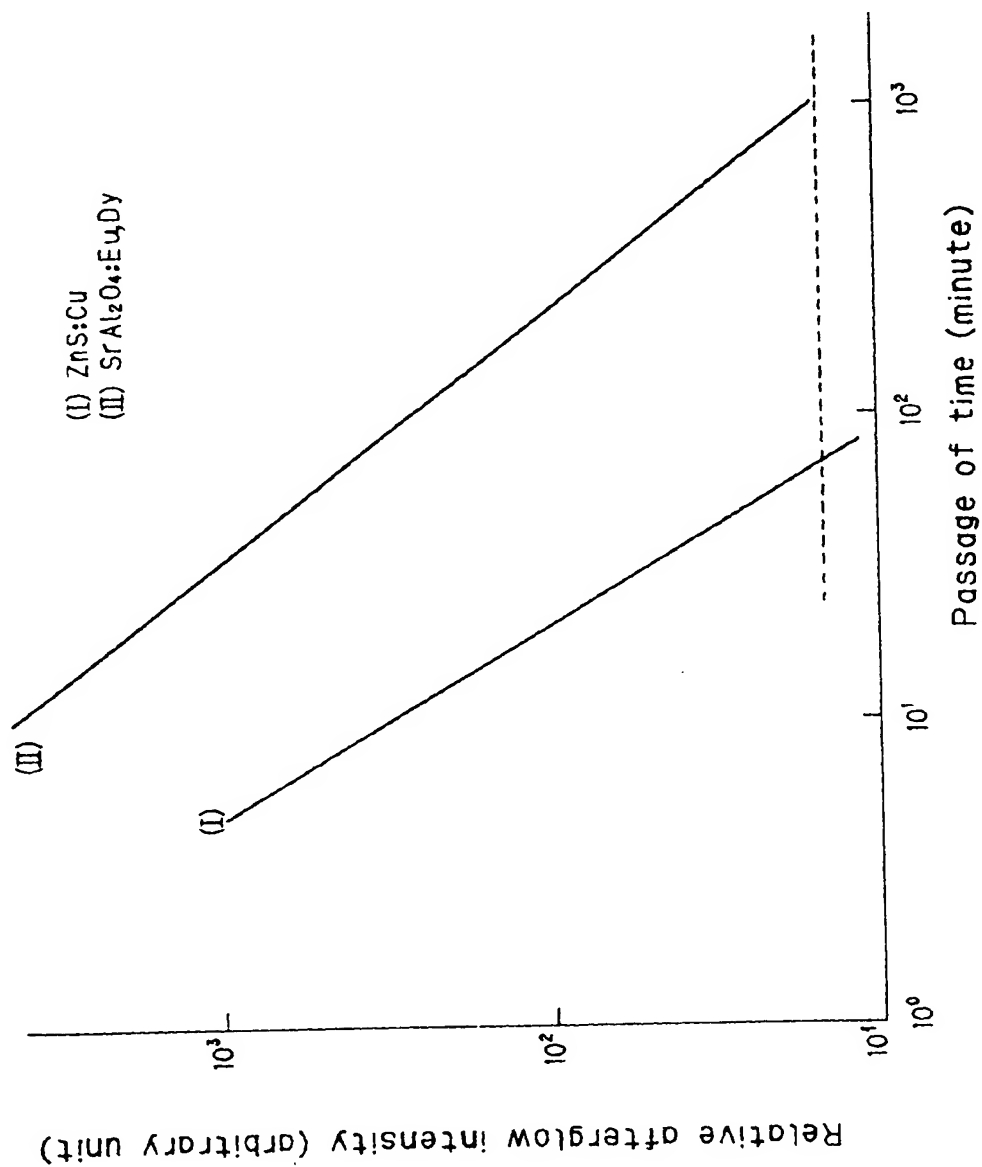


Fig. 5



**Fig.6**

- (I) 20 seconds after irradiation of D65 standard light for 1 second  
(II) 20 seconds after irradiation of D65 standard light for 2 seconds  
(III) 20 seconds after irradiation of D65 standard light for 4 seconds

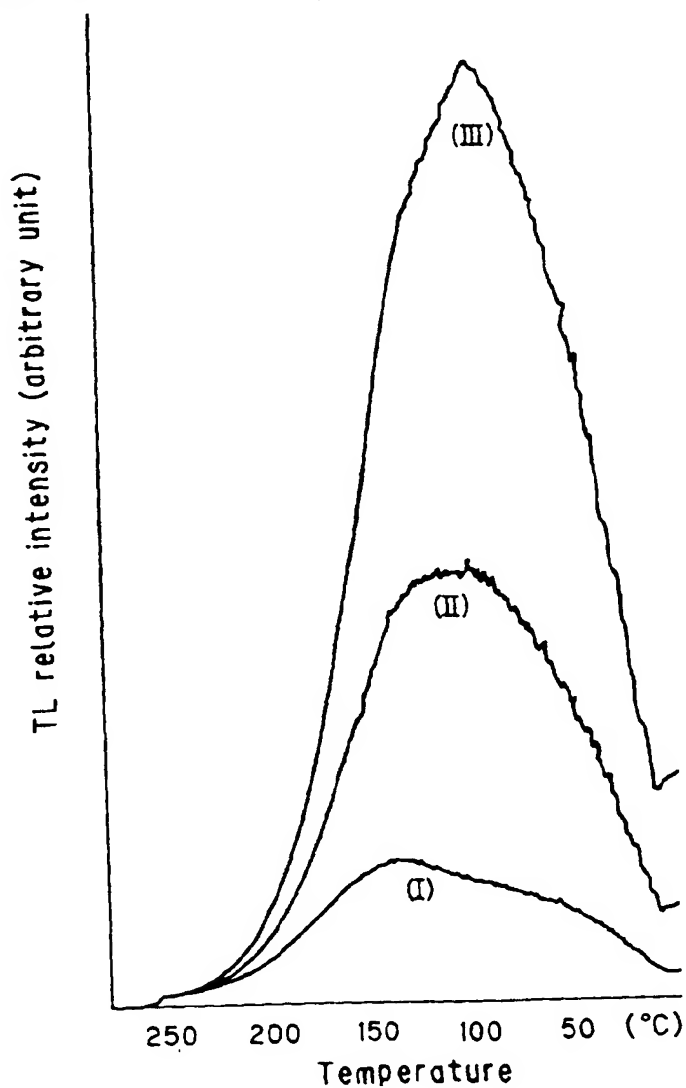


Fig.7

- (I) 20 seconds after irradiation of D65 standard light for 2 seconds  
(II) 20 seconds after irradiation of D65 standard light for 4 seconds  
(III) 20 seconds after irradiation of D65 standard light for 6 seconds

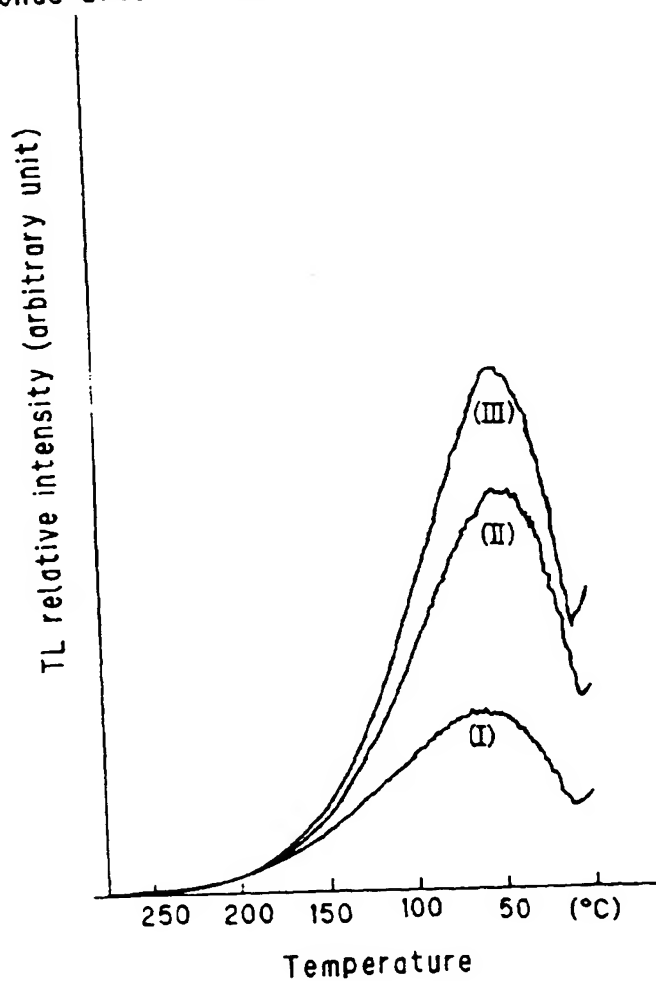


Fig. 8

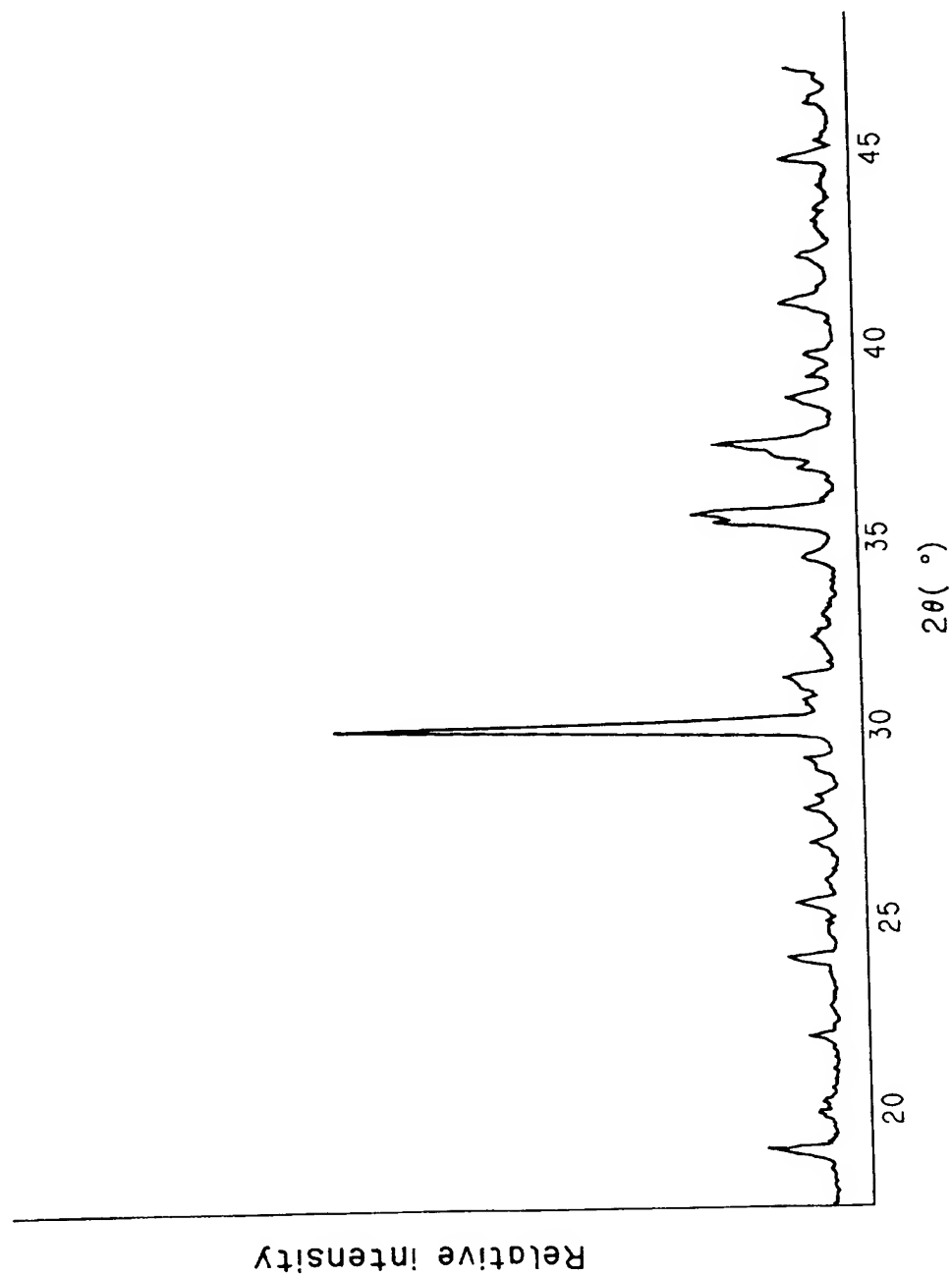
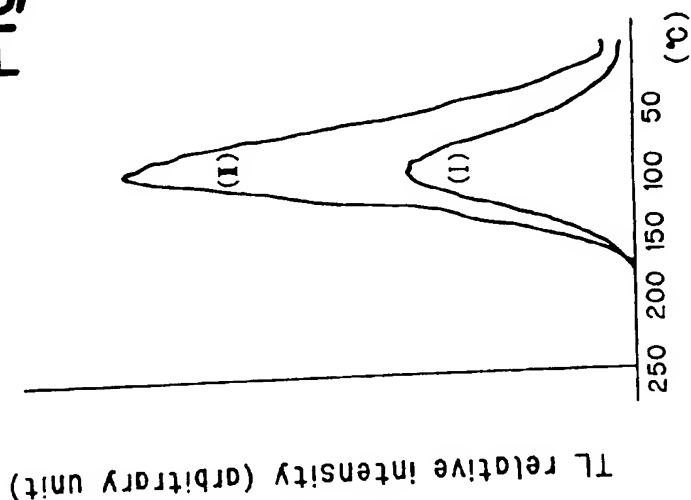
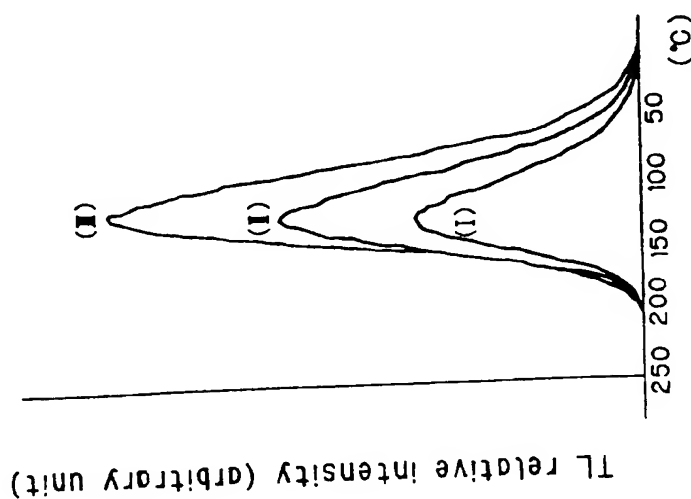


Fig. 9



5-(16)

- (I) 20 seconds after irradiation of D65 standard light for 15 seconds
- (II) 20 seconds after irradiation of D65 standard light for 30 seconds

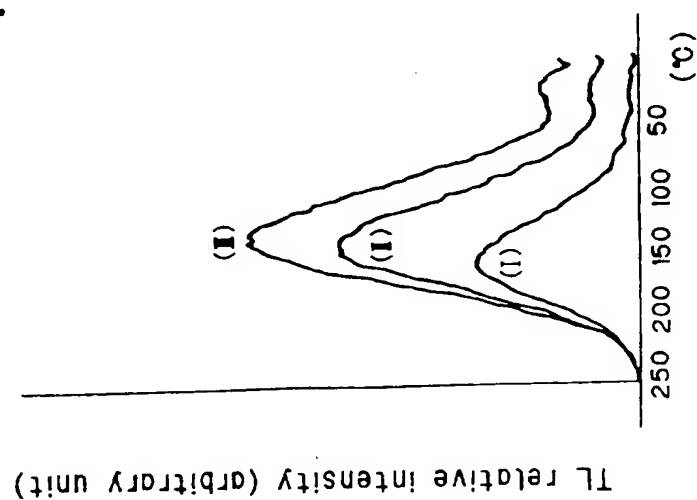


5-(10)

- (I) 20 seconds after irradiation of D65 standard light for 10 seconds
- (II) 20 seconds after irradiation of D65 standard light for 15 seconds
- (III) 20 seconds after irradiation of D65 standard light for 20 seconds

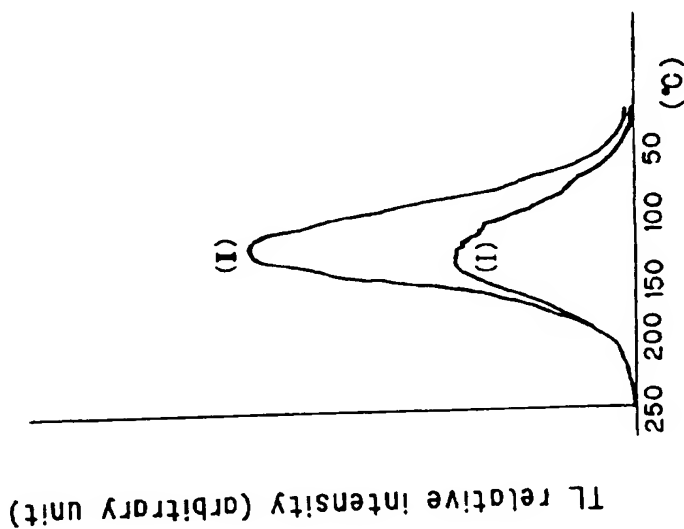


Fig.10



5-(22)

- (I) 20 seconds after irradiation of D65 standard light for 10 seconds
- (II) 20 seconds after irradiation of D65 standard light for 15 seconds
- (III) 20 seconds after irradiation of D65 standard light for 20 seconds



5-(28)

- (I) 20 seconds after irradiation of D65 standard light for 15 seconds
- (II) 20 seconds after irradiation of D65 standard light for 30 seconds

Fig.11

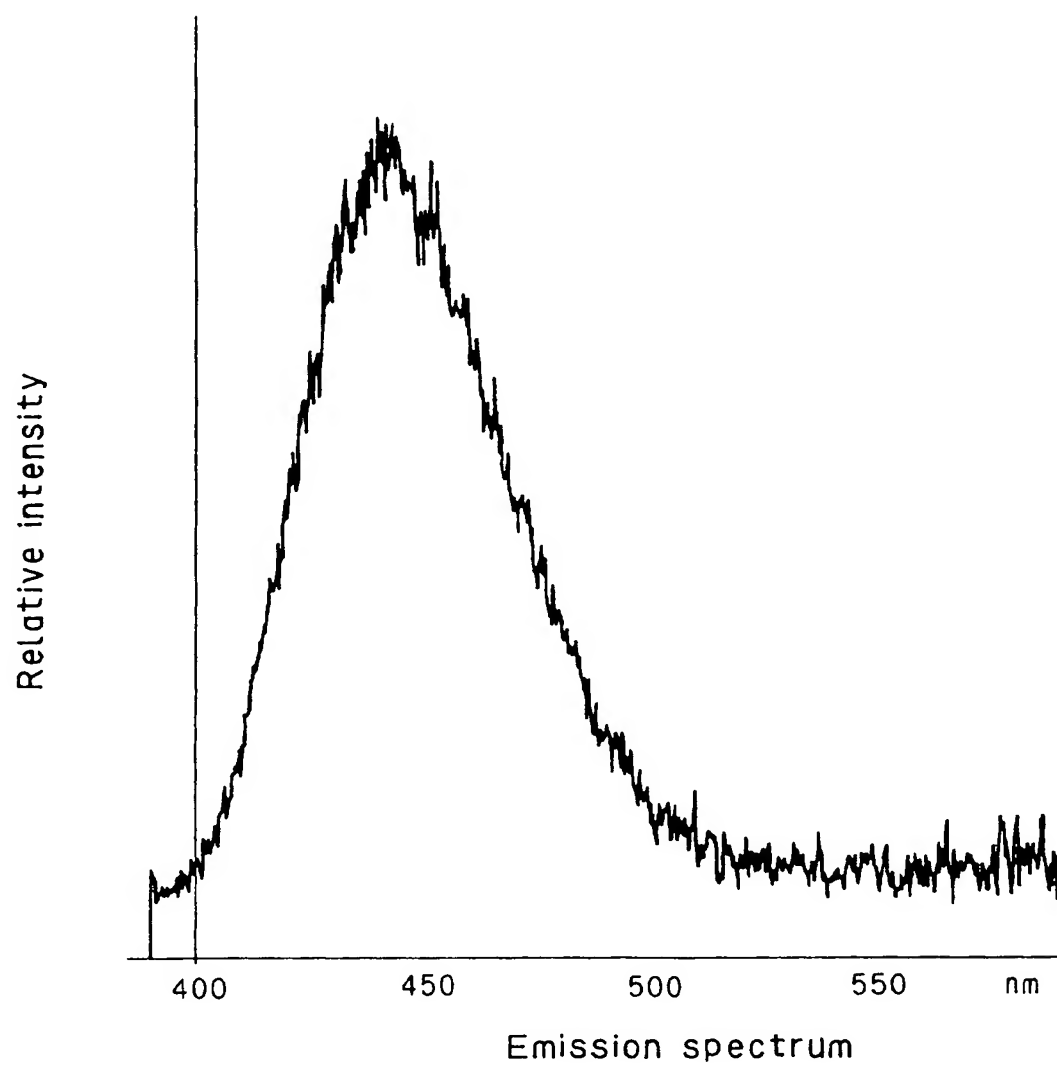


Fig.12

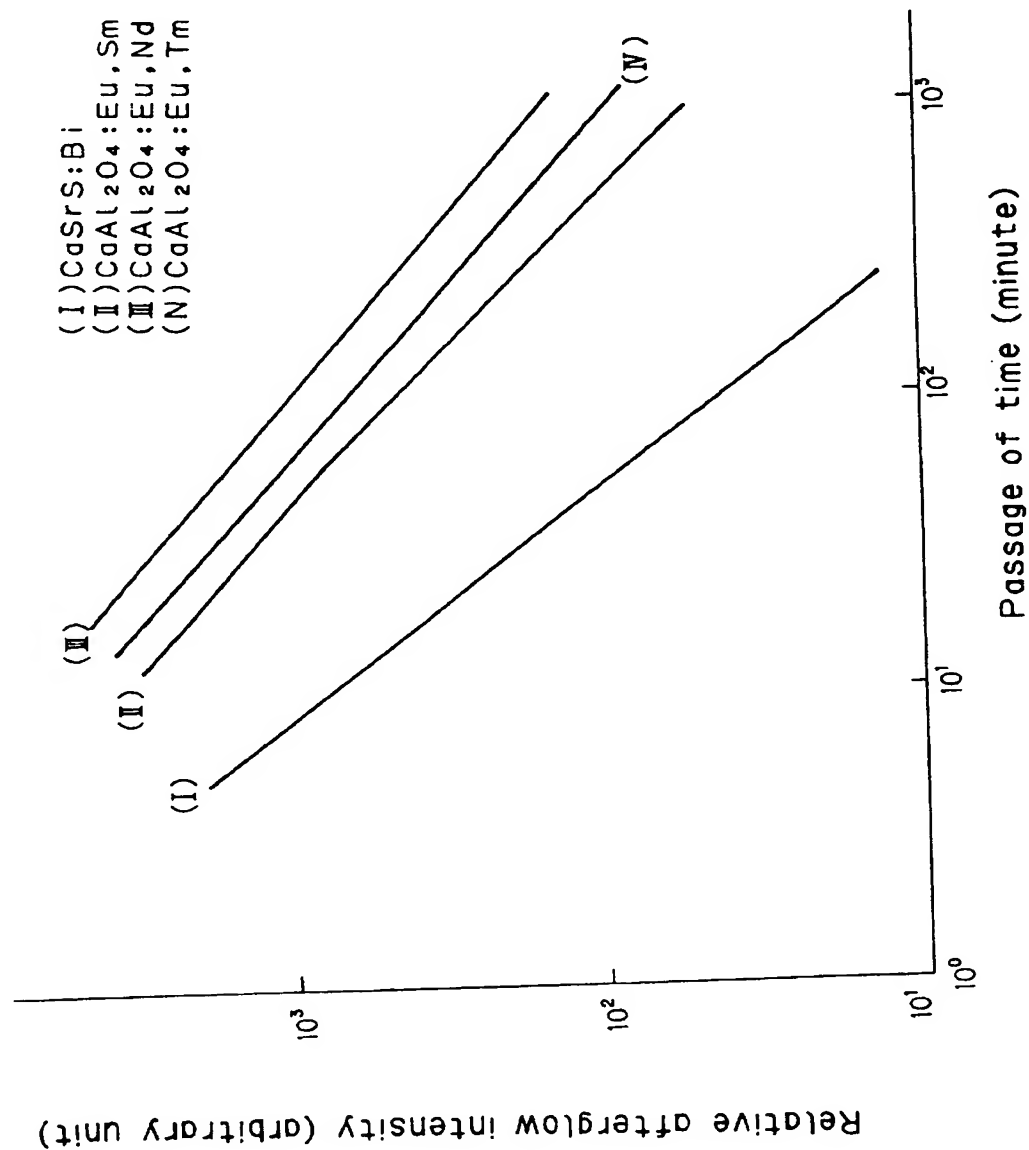


Fig.13

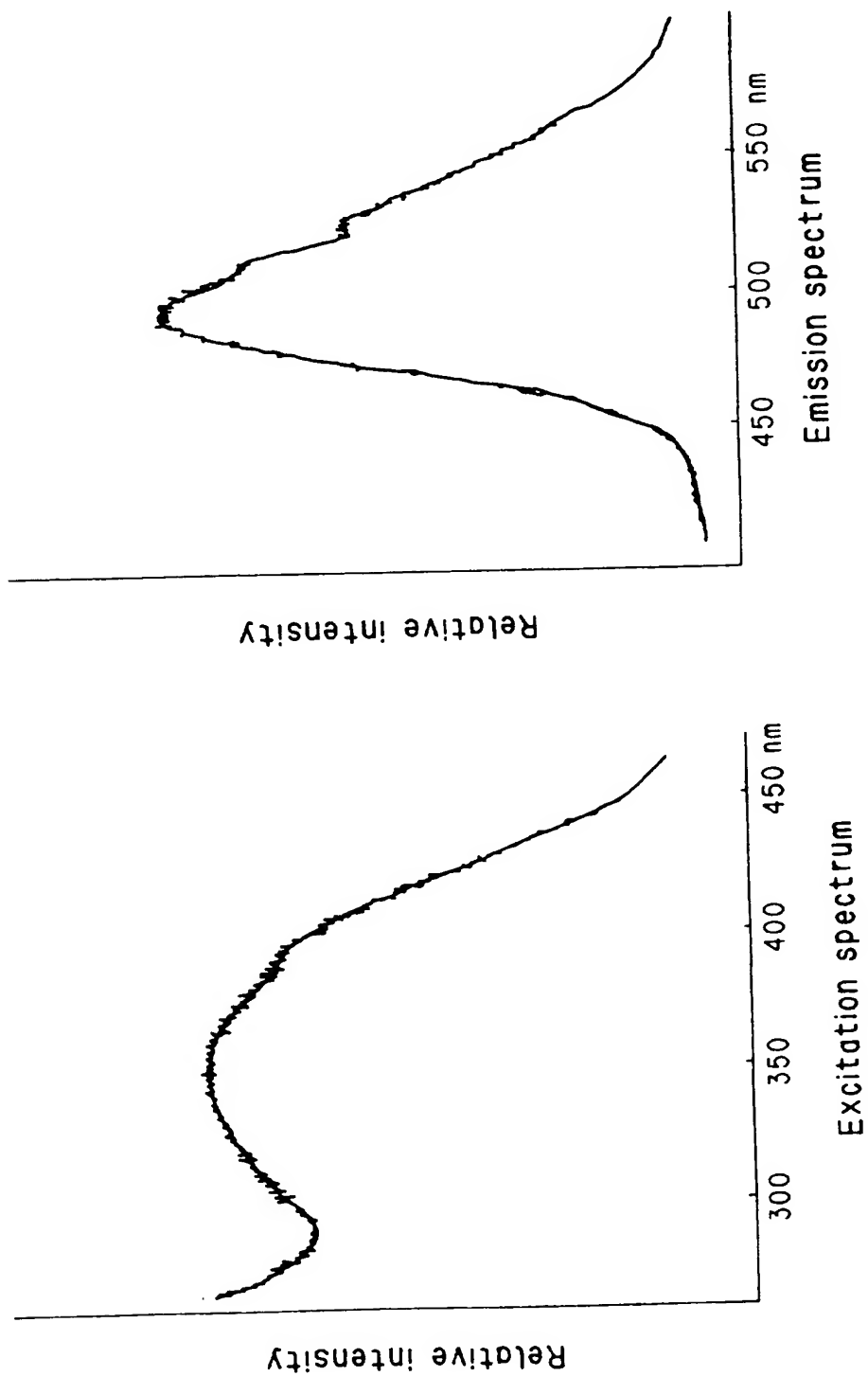


Fig.14

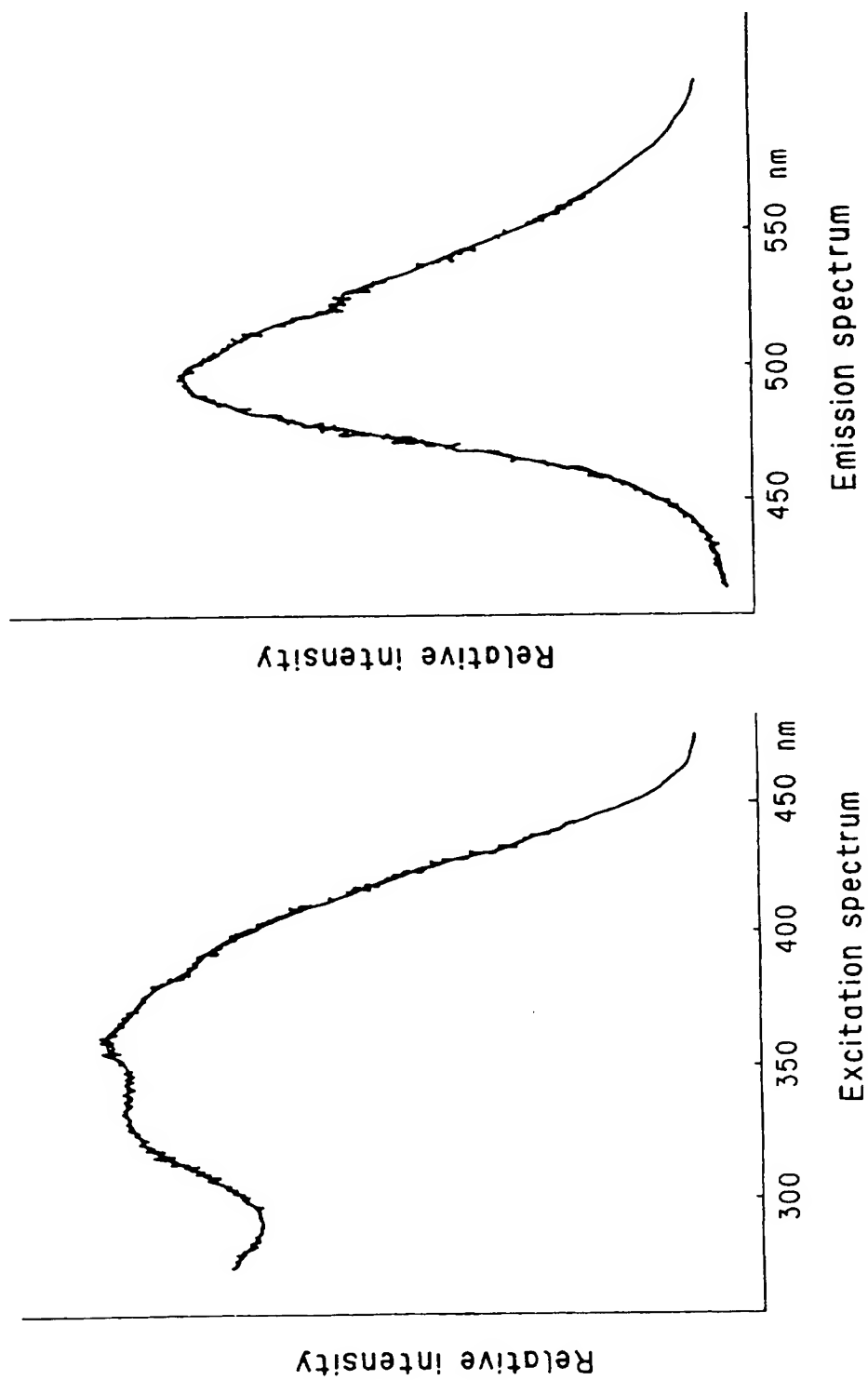


Fig.15

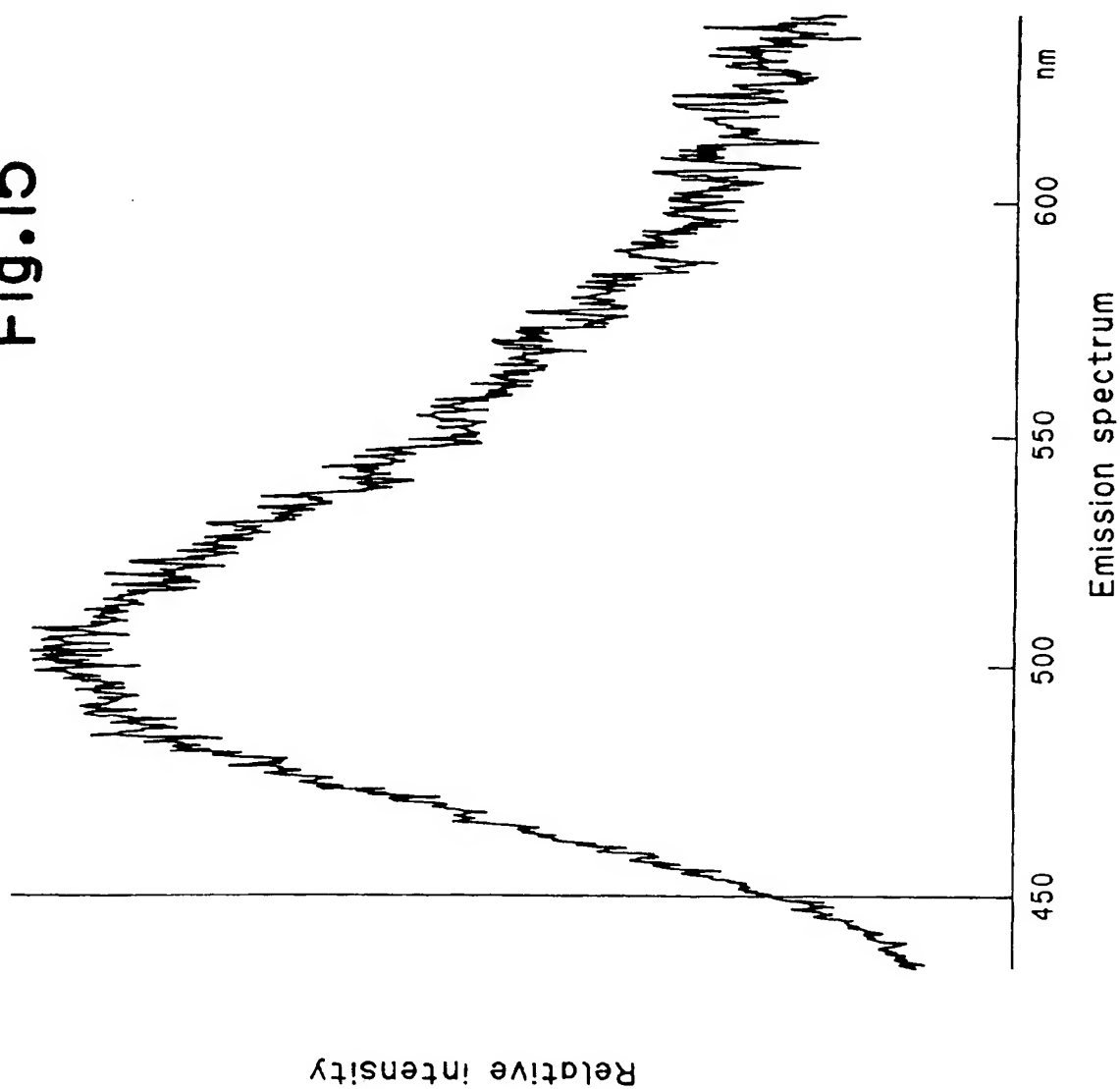


Fig.16

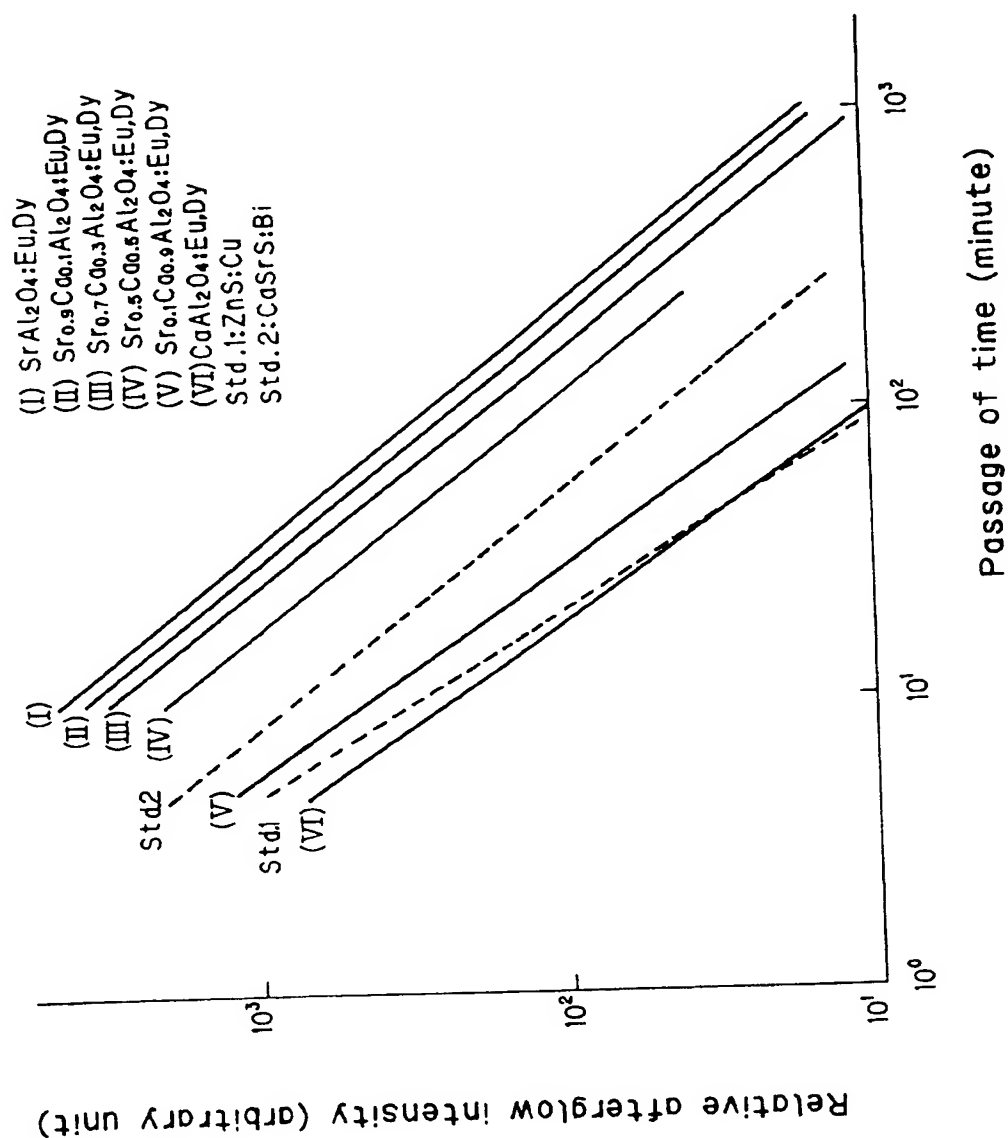


Fig.17

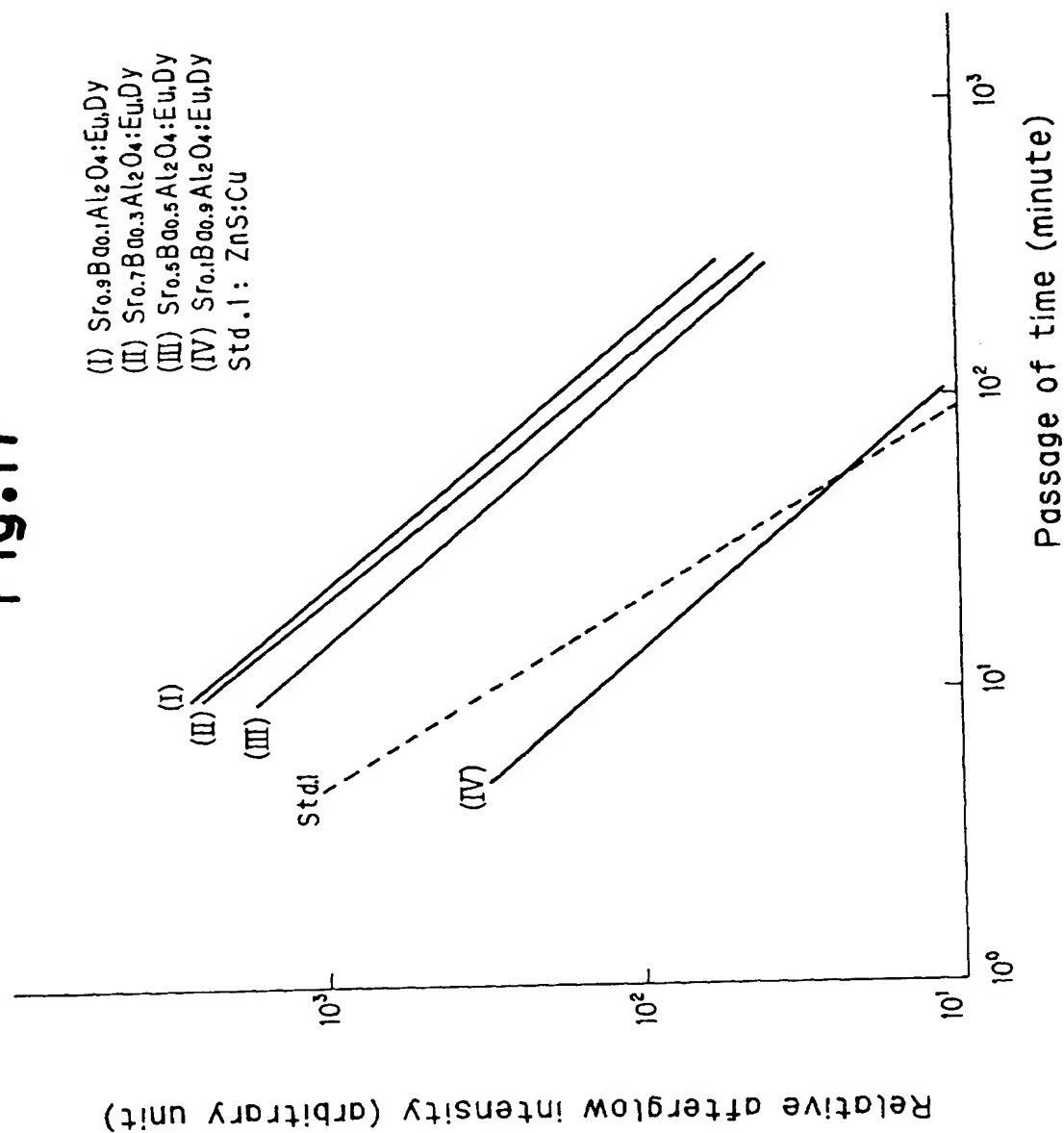




Fig.18

